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REPORT ON SULFUR DIOXIDE STUDY

Iowa Department of Environmental Quality

October 1975

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PB 253 157

REPORT
on
SULFUR DIOXIDE STUDY

1975

IOWA DEPARTMENT OF ENVIRONMENTAL QUALITY

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This is a six-month study of two Iowa power plants for the purposes of: 1) determining the feasibility of utilizing high sulfur coal in Iowa's coal burning electric generating units, while concurrently attaining and maintaining the National Ambient Air Quality Standards (NAAQS) for SO_2, and 2) developing a diffusion model for use in Iowa to determine compliance of other SO_2 emitting sources with the NAAQS. This report includes a description of the methods used in the study, data collected, tables and figures, and progress reports.

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17c. COSATI Field/Group

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IOWA
SULFUR DIOXIDE STUDY
REPORT

October, 1975

Prepared By

Air Quality Management Division

Iowa Department of Environmental Quality

Des Moines, Iowa

ACKNOWLEDGEMENTS

The success of the project described in this report was made possible through the coordination and cooperation of many agencies and organizations. The legislative appropriation covered only a fraction of the total cost of this research and therefore special recognition is in order for the assistance given to DEQ by gathering and providing information. These groups are the State Hygienic Laboratory at the University of Iowa; the Department of Climatology and Meteorology, Electrical Engineering, and the Physical Plant at Iowa State University; the Iowa Coal Research Project; Iowa Power and Light Company; the Iowa Energy Policy Council; the Iowa State Commerce Commission; the Iowa Geological Survey; the Des Moines-Polk County Health Department; and the University of Wisconsin.

ERRATA

to the

Sulfur Dioxide Study

1. Page 9

   Title, line 3, should read:
   "BASED UPON 1951-1960, FEB., MARCH AND APRIL METEROLOGICAL DATA"

2. Page 48

   last paragraph, add new sentences:
   Stack #1 has a stack height of 195 feet and a distance of 8 feet. Stack #2 is 135 feet high with a diameter of 8 feet.

3. Page 49

   first paragraph, add new sentences:
   Stack #1, serving Unit #10, is 250 feet high and 12 feet in diameter. Stack #2, serving Until #11, has a height of 250 feet and a diameter of 10 feet.

4. Page 109

   last paragraph, line 8, add:
   "the maximum concentration predicted by the diffusion model under the meteorological parameters recorded during the study period."

5. Page 110

   first paragraph, last line, should be:
   "the study was designed ..."

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INTRODUCTION

In 1974, the Iowa Legislature appropriated for DEQ funds totaling $133,000 for the purpose of conducting a comprehensive sulfur dioxide (SO_2) study. The primary purpose of the study was to determine the feasibility of utilizing high sulfur coal in Iowa's coal burning electric generating units, while concurrently attaining and maintaining the National Ambient Air Quality Standards (NAAQS) for SO_2 (See Table 1). A second purpose of this study was to develop a diffusion model for use in Iowa to determine compliance of other SO_2 emitting sources with the NAAQS. The diffusion model itself consists of a series of mathematical equations which are designed to predict the path and concentration of pollutants emanating from various air pollution sources.

With these purposes in mind, the Iowa Department of Environmental Quality (DEQ) selected two power plants in Iowa for detailed study. Because of the plant size and their proximity to DEQ offices, the power plants chosen were 1) Physical Plant, Iowa State University, Ames, Iowa, and 2) Iowa Power & Light Company, Station No. 2, Des Moines, Iowa. The heat input of the boilers involved in the Ames portion of the study are normally: Unit #1 - 106.9 MMBTU/Hr.; Unit #2 - 106.9 MMBTU/Hr.; Unit #3 - 220.1 MMBTU/Hr.; Unit #5 - 201.7 MMBTU/Hr.; and Unit #6 - 105.6 MMBTU/Hr. The heat inputs of the boilers involved in the Des Moines portion of the study are normally: Unit #10 - 780 MMBTU/Hr. and Unit #11 - 1085 MMBTU/Hr.

Since the allocated funds were based on a six-month study, each power plant was only studied for a period of 3 months. For the Ames facility, the study period was from November, 1974, through January, 1975. February, March and April of 1975 were devoted to Iowa Power in Des Moines.

Figure 1 is a sketch illustrating some of the instruments operated during the SO_2 study. While this figure does not show all of the instruments utilized in the study, several important ones are shown. A balloon system, labeled as 1, was utilized to provide ambient temperature profile data. This data is available for analysis but as of this writing, manpower restrictions limit the inclusion of that data into this report. Number 2 refers to the wind speed and direction indicators located atop two of the monitoring trailers, which are labeled as number 3. The trailers are equipped with ambient SO_2 monitoring instruments and associated recording equipment.

Most of the analysis of the meteorological data obtained during the course of the study was performed by the Department of Climatology and Meteorology, Iowa State University, Ames, Iowa. This analysis was performed under contract with the Iowa State University staff and provided for the submission of first, second, and final reports of their studies. These reports are included as Appendices A, B, and C of this report in order to provide more detailed information as to the meteorological data analysis.

Attention is directed to the maps, Figures 2 and 3, representing the relative location of instrumentation operations surrounding the study sites. Various items of equipment shown on these maps will be discussed in further portions of this report.

TABLE 1

NATIONAL PRIMARY AND SECONDARY
AMBIENT AIR QUALITY STANDARDS

Published in the Federal Register, Vol. 36, No. 84
Part II - Friday, April 30, 1971

Revised in the Federal Register, Vol. 38, No. 178
Part I - Friday, September 14, 1973

Sulfur Dioxide

Primary	Secondary	
a) 80 $\mu g/m^3$ (0.03 ppm)		Annual arithmetic mean
b) 365 $\mu g/m^3$ (0.14 ppm)		Maximum 24-hour concentration not to be exceeded more than once per year.
	1300 $\mu g/m^3$ (0.5 ppm)	Maximum 3-hour concentration not to be exceeded more than once per year.

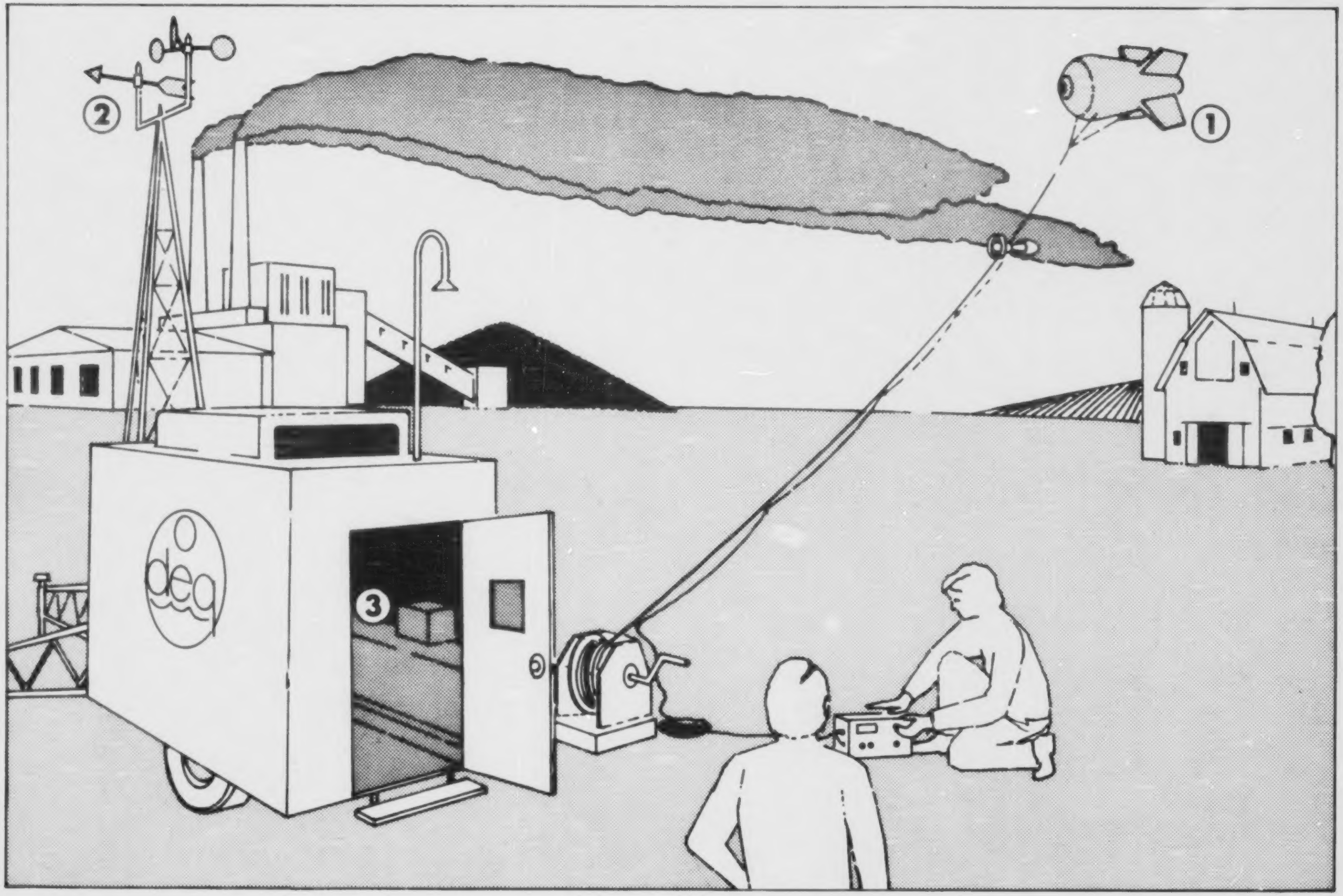


FIGURE 1 Instrumentation Layout for the Sulfur Dioxide Study

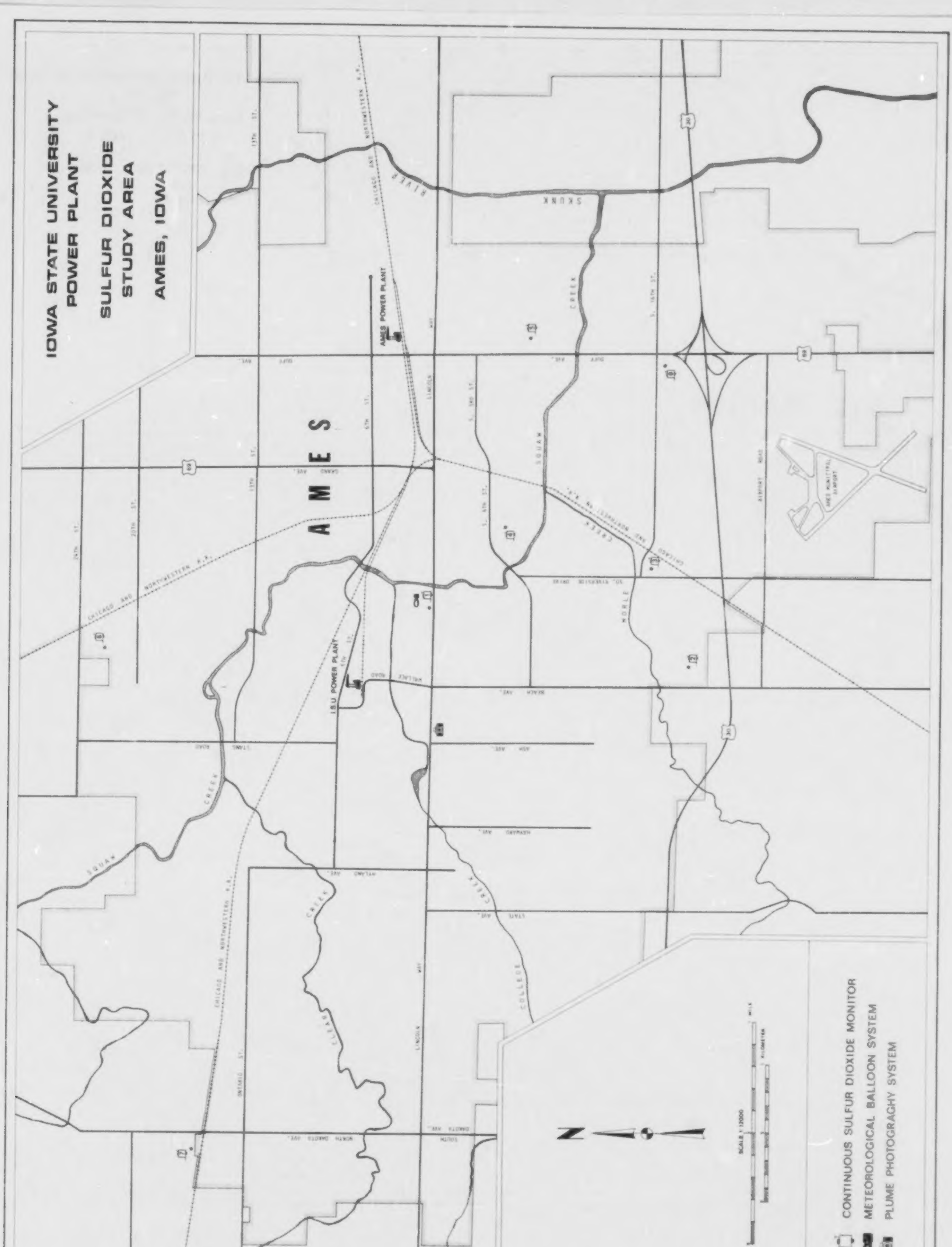

IOWA STATE UNIVERSITY
POWER PLANT
SULFUR DIOXIDE
STUDY AREA
AMES, IOWA
AMES
ISU POWER PLANT
AMES POWER PLANT
SKUNK RIVER
SQUAW CREEK
COLLEGE CREEK
CLEAR CREEK
WORLE CREEK
CHICAGO AND NORTHWESTERN R.R.
24TH ST.
20TH ST.
13TH ST.
6TH ST.
GRAND AVE.
LINCOLN WAY
S. 3RD ST.
S. 4TH ST.
S. 16TH ST.
DUFF AVE.
SO. RIVERSIDE DRIVE
AIRPORT ROAD
AMES MUNICIPAL AIRPORT
WALLACE ROAD
BEACH AVE.
STANGE ROAD
ASH AVE.
HAYWARD AVE.
HYLAND AVE.
STATE AVE.
ONTARIO ST.
NORTH DAKOTA AVE.
SOUTH DAKOTA AVE.
30
69
N
SCALE 1:12000
MILE
KILOMETER
CONTINUOUS SULFUR DIOXIDE MONITOR
METEOROLOGICAL BALLOON SYSTEM
PLUME PHOTOGRAGHY SYSTEM

Figure 2

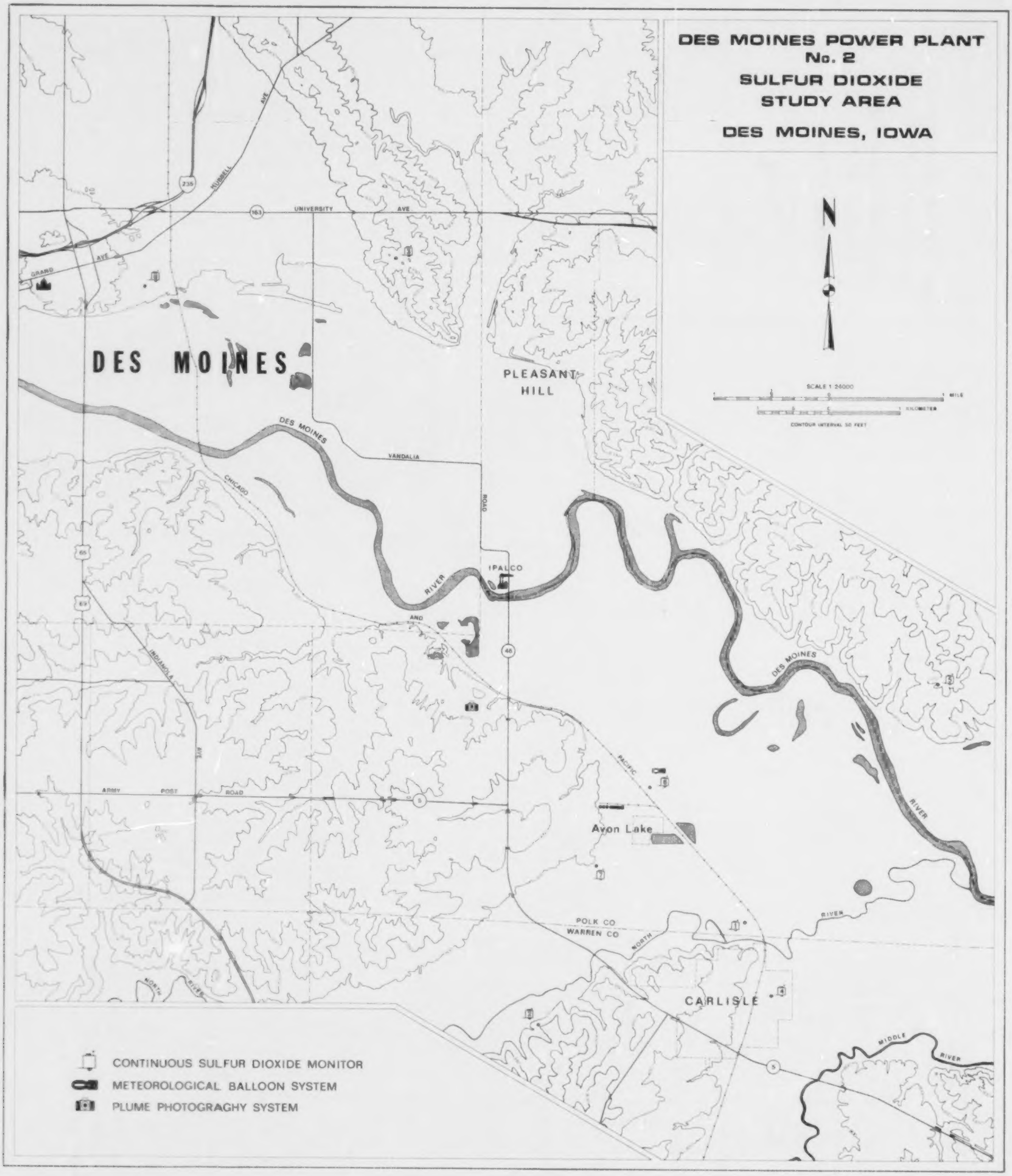

DES MOINES POWER PLANT
No. 2
SULFUR DIOXIDE
STUDY AREA
DES MOINES, IOWA
N
SCALE 1:24000
MILE
KILOMETER
CONTOUR INTERVAL 50 FEET
DES MOINES
PLEASANT HILL
IPALCO
Avon Lake
CARLISLE
UNIVERSITY AVE
GRAND AVE
HUBBELL AVE
VANDALIA ROAD
DES MOINES RIVER
CHICAGO AND NORTH PACIFIC
INDIANOLA AVE
ARMY POST ROAD
POLK CO
WARREN CO
NORTH RIVER
MIDDLE RIVER
235
163
65
69
46
5
CONTINUOUS SULFUR DIOXIDE MONITOR
METEOROLOGICAL BALLOON SYSTEM
PLUME PHOTOGRAGHY SYSTEM

Figure 3

AMBIENT AIR MONITORS

The first step in preparing for the aquisition of data was to locate the necessary air monitoring equipment. It was desirable to locate these monitors such that they could reasonably be expected to monitor the maximum ground-level concentrations from the sources. To accomplish this, a preliminary diffusion modeling study was undertaken to provide guidelines in locating the monitors. This preliminary work relied upon wind speed and direction frequencies to establish the most likely areas of maximum concentration. The polar charts shown in Figures 4 and 5 illustrate the results of these preliminary studies in and around Ames and Des Moines, respectively. Each segment of the chart is assigned a % relative probability. The higher this value, the more likely that the maximum ground level concentration would occur in that area. With these priorities in mind, DEQ staff then surveyed the various areas to seek possible sites for the monitors. Consideration was given to the ease of access to electrical power, possible effects of the terrain or the air flow, and ease of serviceability. Upon completion of these surveys, the final sites for the monitors were selected, as denoted in the polar charts. Funds permitted the purchase of 7 SO_2 monitors with associated trailers, recorders, and other necessary equipment. The mobile laboratory operated by the State Hygienic Laboratory was also used, providing a system of eight air monitors. The configuration of air monitors was such that at least one was at all times located upwind from the power plant to obtain background data. Background data would indicate the relative influence of the power plant emissions upon the downwind SO_2 concentrations.

LOCATION OF MAXIMUM GROUND LEVEL SULFUR DIOXIDE CONCENTRATION
AT
POWER PLANT, IOWA STATE UNIVERSITY, AMES, IOWA
BASED UPON 1951-1960, NOV., DEC., & JAN. METEOROLOGICAL DATA

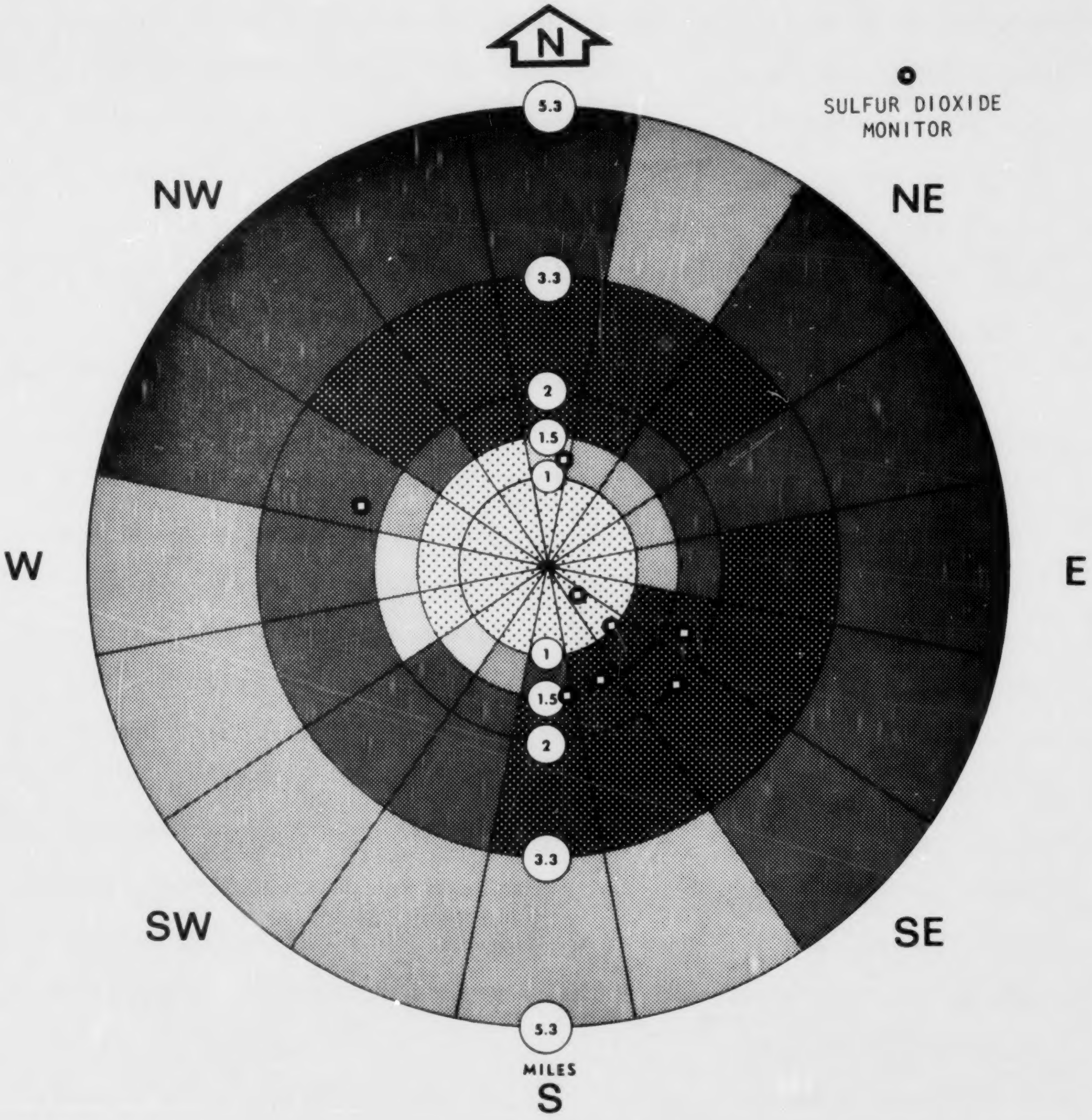


FIGURE 4

.00 .25 .50 1.00 2.00 5.00

% RELATIVE PROBABILITY OF MAXIMUM GROUND LEVEL SULFUR DIOXIDE CONCENTRATION

LOCATION OF MAXIMUM GROUND LEVEL SULFUR DIOXIDE CONCENTRATION
AT
IOWA POWER AND LIGHT CO., DES MOINES, IOWA
BASED UPON 1951-1960, NOV., DEC., & JAN. METEOROLOGICAL DATA

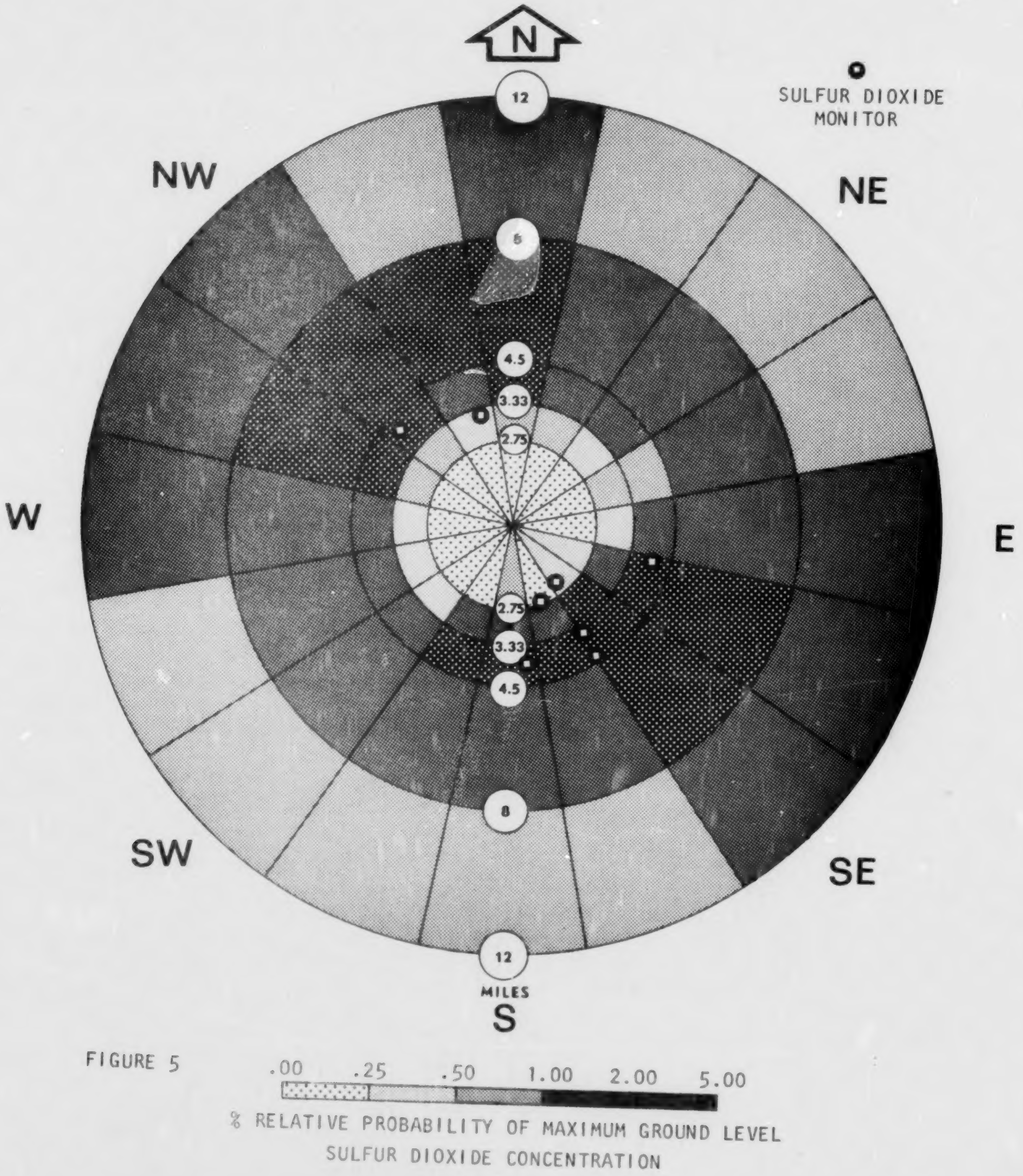


FIGURE 5

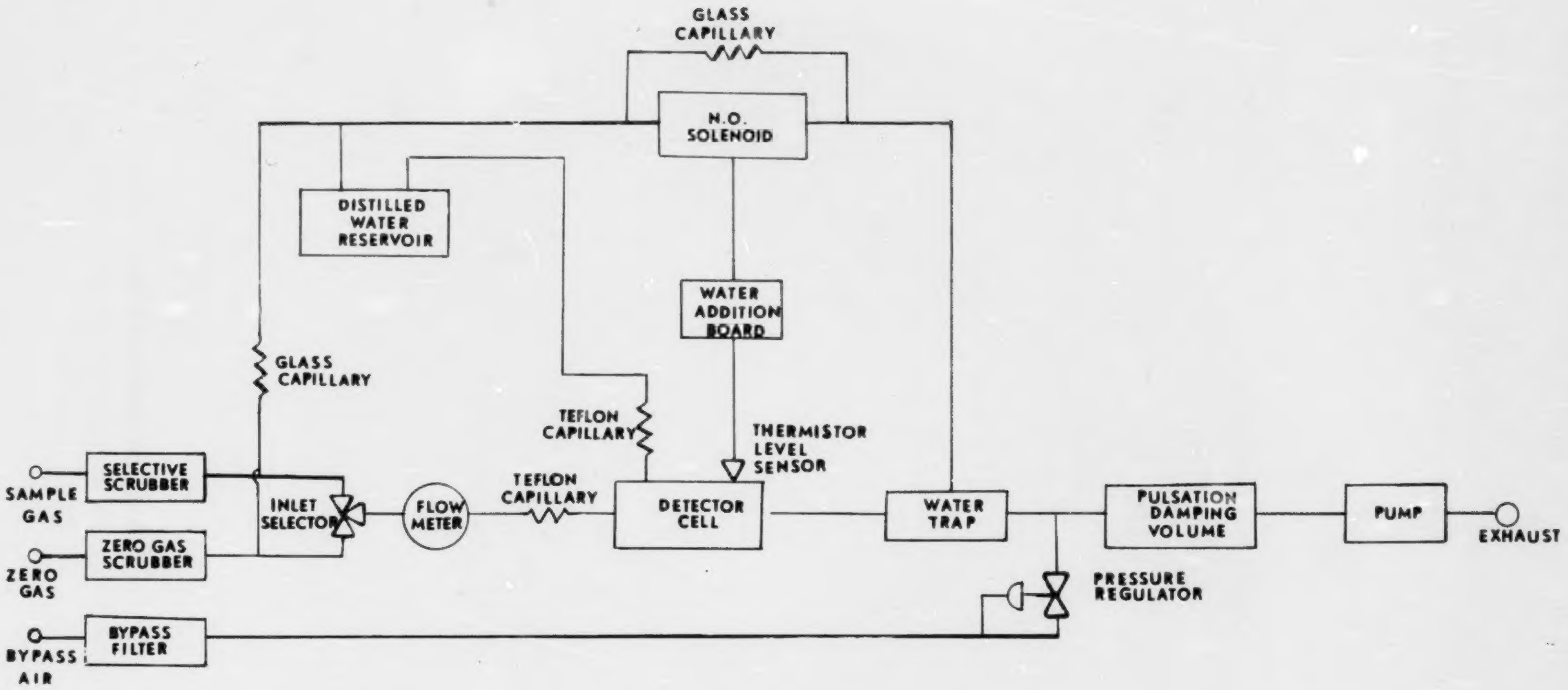

GLASS CAPILLARY
N.O. SOLENOID
DISTILLED WATER RESERVOIR
WATER ADDITION BOARD
GLASS CAPILLARY
TEFLON CAPILLARY
THERMISTOR LEVEL SENSOR
SAMPLE GAS
SELECTIVE SCRUBBER
INLET SELECTOR
FLOW METER
TEFLON CAPILLARY
DETECTOR CELL
WATER TRAP
PULSATION DAMPING VOLUME
PUMP
EXHAUST
ZERO GAS
ZERO GAS SCRUBBER
PRESSURE REGULATOR
BYPASS AIR
BYPASS FILTER

FIGURE 6 Flow diagram of sulfur dioxide ambient monitor.

A representative flow diagram of the air monitoring system employed is shown in Figure 6. The trailers used to house the air monitoring system are shown in Figure 1, labeled as number 3.

Because it was necessary in further portions of the study, a coordinate system was assigned to the air monitoring sites relative to the associated power plant. All coordinates were determined with respect to the base of the power plant stacks. X coordinates follow an east-west line with east being positive X. Y coordinates follow a north-south line with north being positive Y. Elevations, or Z coordinates, were determined using topographic maps, with the base of the power plant stacks having a Z coordinate equal to zero. The resulting coordinates for the Ames portion of the study are shown in Table 2. Those for the Des Moines portion are shown in Table 3. These coordinates, relative to the power plant, are best understood by referring to the maps of the Ames and Des Moines areas, shown on pages 5 and 6 respectively.

TABLE 2

SITE COORDINATES

AMES, IOWA

SITE	X (KM)	Y (KM)	Z (M)
Physical* Plant	0	0	0
1	0.533	-0.495	-3.048
2	0.131	-2.390	4.740
3	0.838	-2.112	-5.624
4	1.113	-1.036	-6.538
5	2.524	-1.173	-8.367
6	0.232	1.753	14.494
7	-3.453	1.533	1.387
8	2.341	-2.188	-1.966

*Physical plant is used as reference for monitor coordinates. Y axis corresponds to N-S on map, N being positive Y. X axis correspondes to E-W on map, E being positive X.

TABLE 3

SITE COORDINATES

Des Moines, Iowa

Site	X (KM)	Y (KM)	Z (M)
Power * Plant	0	0	0
1	3.47	-4.72	1.52
2	0.56	-6.18	19.81
3	-1.54	4.61	51.81
4	3.87	-5.71	1.52
5	6.15	-1.28	41.14
6	2.10	-2.82	3.04
7	1.35	-3.94	6.40
8	-5.06	4.17	19.20

*Power plant is used as reference for monitor coordinates. Y axis corresponds to N-S on map, N being positive Y. X axis corresponds to E-W on map, E being positive X.

PHOTOGRAPHIC SYSTEM

In addition to the air monitoring system, DEQ established a photographic system to provide information on the actual path followed by a plume under varying atmospheric conditions. The photographic sites, as shown on the maps on pages 5 and 6, are oriented such that the photos would be taken perpendicular to the primary direction of plume travel.

The photographic system itself consisted of an 8 millimeter (mm) movie camera, a 35 millimeter (mm) camera, automatic timing devices, and a clock. The system was designed such that the 8mm movie camera operated during daylight hours taking photos at the rate of one frame exposure every minute. The 35mm camera was operated during the nighttime, taking pictures at the rate of one frame exposure every three minutes. The clock was located outside the camera system housing in such a position that it was visible in each frame of the photos taken. This provided an accurate record of the time of each frame's exposure.

After the photos had been taken and developed, a procedure for their analysis was established.[2] This procedure involved taking specific measurements from the photos. The photos were enlarged to readable size using a microfilm projector for 8mm film and a film strip projector for the 35mm film. The projected image was much like that illustrated in Figure 7. From these projections, various measurements were taken with the use of a superimposed grid system. On each photo, twelve downwind distances were chosen. At each downwind point, the distances to the top and bottom of the plume were measured (denoted by a and b in Figure 7). The mean of a and b was defined as being the point on the centerline of the plume at that downwind point. The centerline points vs. downwind distances was then compared with the plume centerline predicted by well-known plume rise formulas. A correlation factor could then be derived to "calibrate"

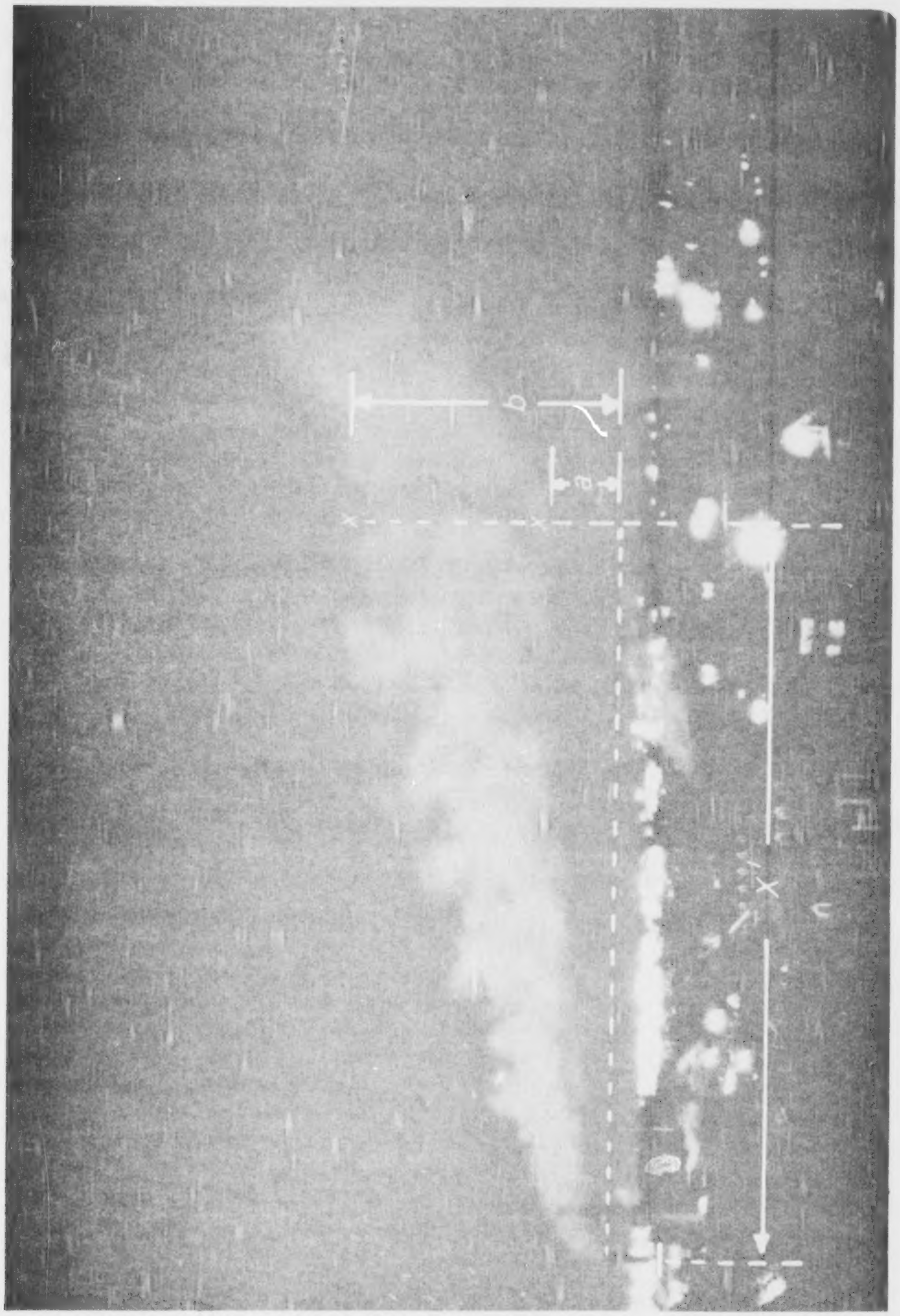


FIGURE 7

the formulas for the various atmospheric conditions existing at the time the photos were taken. The differences between a and b provide an indication of the spreading of the plume. This data can therefore be correlated with atmospheric stability and wind speed information to develop equations to predict the diffusion patterns of the plume. Atmospheric stability is a function of the vertical turbulence of the air. A high degree of vertical turbulence would indicate very unstable atmospheric conditions. Note that generally the more stable the atmosphere and the higher the wind speed, a lesser degree of diffusion would exist in the vertical direction, and hence the smaller the difference between a and b. Because of this the data taken from the photos was classified according to calculated stability classes (explained later in the report) and the recorded wind speed.

As mentioned, a grid system was employed in reading the photos. In order to interpret the grid measurements, a know distance on each photo was measured in terms of grid units. For the Iowa State University power plant, this reference distance was the vertical difference between the tall and short stacks. For Des Moines, the reference distance was the horizontal difference between two stacks.

POWER PLANT OPERATIONS

In order to provide a correlation between monitored ambient air concentrations of SO_2 and the emission rate of SO_2 from the power plants, it was necessary to gather pertinent power plant operational data. This information would provide an estimate of the SO_2 emissions based on the coal firing rate and the percent sulfur in the coal. Essential power plant parameters were the volume of exhaust gases from the stacks and the actual stack temperature. Boiler operational data was evaluated to provide these factors.

The coal sampling procedure differed slightly between the ISU and Iowa Power generating plants, but the analysis of the coal remained the same. At the Ames facility, coal samples were taken several times each day, every hour if possible. The samples themselves were taken from the headhouse, where the coal changes conveyors en route from the coal pile to the coal bunkers. Upon accumulation of the appropriate amount of sample (approximately 5 gallons), the aggregate sample was reduced and ground. The sample was then weighed and sent to a laboratory for analysis. The laboratory analysis consisted of drying the sample, then determining the heating value (BTU/pound), the percent sulfur, and the percent ash, all on a dry basis. The percent moisture in the coal was determined based upon comparison of the dried sample with the original sample weight. The percent moisture could then be applied to the heating value, % sulfur, and % ash to obtain those values on an "as received" basis. The coal sample procedure for Iowa Power was much the same except the samples were taken at the coal bunkers serving the two boilers, Nos. 10 and 11.

Boiler operating data was obtained to facilitate calculation of the coal firing rate. At ISU, the temperature and pressure of the feedwater and the steam were used to determine the enthalpy difference across the boiler. Using this and the boiler's design efficiency, the total heat input could be calculated. Knowing the heating value of the coal, the coal firing rate could be obtained. The coal firing rate multiplied by the % sulfur in the coal would then give the pounds of sulfur fired into the boiler per hour.

At Iowa Power, data on the megawatt generation of the boilers was available. This megawatt generation was referenced to boiler efficiency charts to directly determine the BTU per hour heat input. The pounds of sulfur fired into the boiler per hour could then be determined the same as for ISU.

Theoretically, from the pounds of sulfur burned per hour, one could determine the SO_2 emission rate. Yet, it is a known fact that not all the sulfur is oxidized and, if oxidized, all the sulfur dioxide does not reach the stack. Sulfur may remain in the slag and ash in various chemical forms, thereby reducing the amount of SO_2 emitted. Possible routes of sulfur and SO_2 through a boiler are shown in Figures 8 and 9, representing the Ames and Des Moines boilers respectively. In order to determine the percentage of the sulfur in the coal that is converted into SO_2 and the percentage of that SO_2 which is finally emitted through the stack, DEQ utilized an in-stack SO_2 monitor to directly measure the SO_2 emission rate. A typical in-stack monitoring system is shown in Figure 10. The SO_2 emission rate measured could then be compared to the pounds of sulfur fired into the boiler per hour. A ratio of these two parameters would then provide an indication of the SO_2 conversion rate. Normally, this conversion rate varied between 93 and 100 percent. That is, 93 to 100 percent of the sulfur fired is emitted out the stack as SO_2. This conversion appeared to vary with the type of boiler and the boiler load.

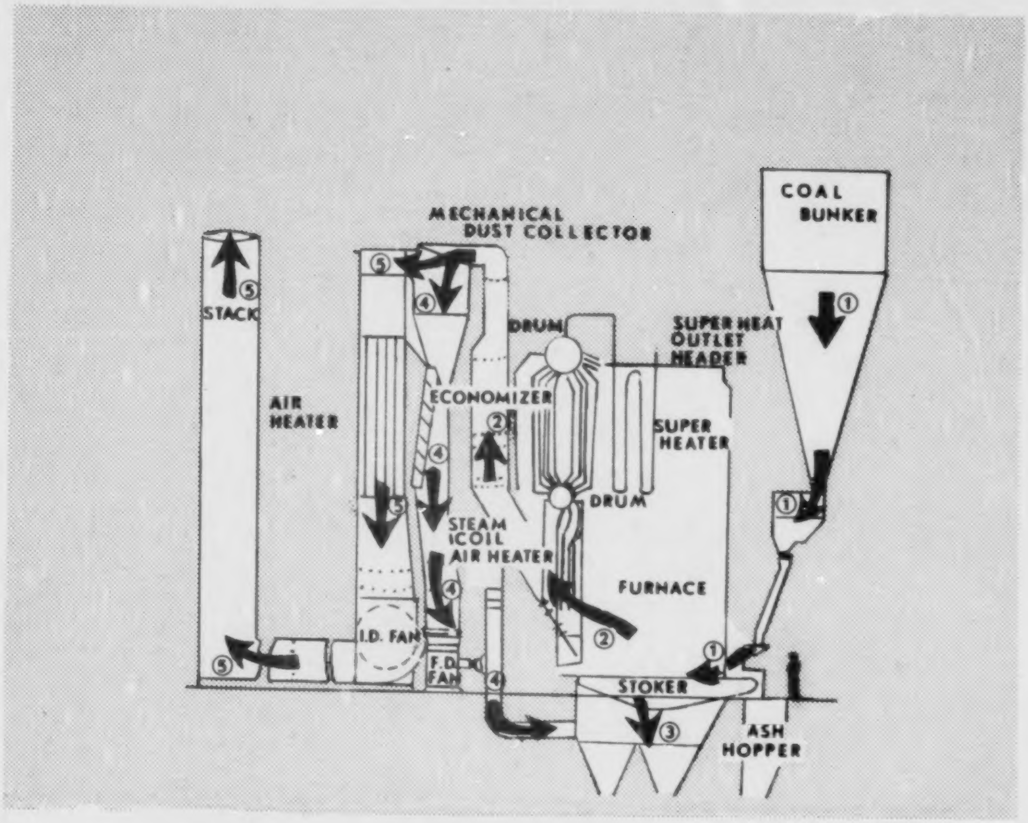

COAL BUNKER
MECHANICAL DUST COLLECTOR
STACK
AIR HEATER
DRUM
SUPER HEAT OUTLET HEADER
ECONOMIZER
SUPER HEATER
DRUM
STEAM COIL AIR HEATER
FURNACE
I.D. FAN
F.D. FAN
STOKER
ASH HOPPER
①
②
③
④
⑤

FIGURE 8

Figure 8 , shows the flow of sulfur and sulfur dioxide through a traveling grate coal -fired boiler.

Legend

① The sulfur enters the boiler when the coal is being fired.

② Upon combustion of the coal, sulfur leaves the boiler either as sulfur dioxide or as sulfur compounds in the entrained fly ash.

③ The sulfur compounds may leave the boiler in the slag or the ash.

④ Sulfur compounds also may leave the boiler system in the particulate collected in the dust control equipment.

⑤ Sulfur dioxide leaves the system.

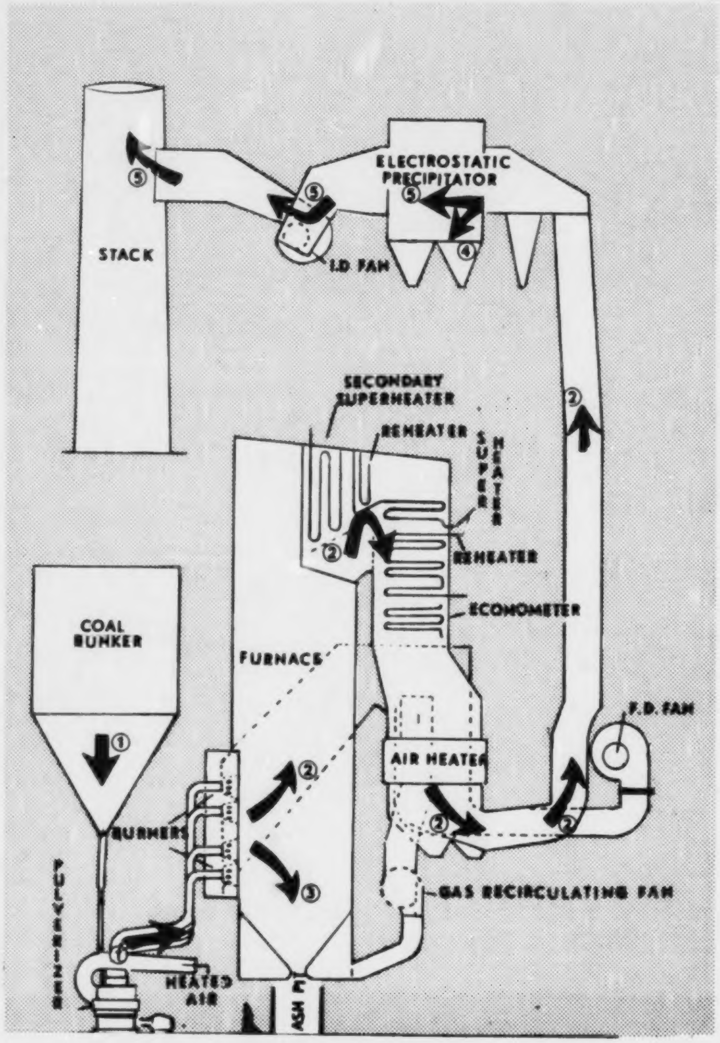

STACK
⑤
⑤
I.D FAN
ELECTROSTATIC PRECIPITATOR
⑤
④
②
SECONDARY SUPERHEATER
REHEATER
SUPERHEATER
②
REHEATER
ECONOMETER
COAL BUNKER
①
FURNACE
AIR HEATER
F.D. FAN
②
②
②
BURNERS
③
GAS RECIRCULATING FAN
PULVERIZER
①
HEATED AIR
ASH

FIGURE 9 Shows the flow of sulfur and sulfur dioxide through a pulverized coal fired boiler.

Legend

① The sulfur enters the boiler when the coal is being fired.

② Upon combustion of the coal, sulfur leaves the boiler either as sulfur or as sulfur compounds in the entrained fly ash.

③ The sulfur compounds also may leave the boiler in the slag or the ash.

④ Sulfur compounds may also leave the boiler system in the particulate collected in the dust control equipment.

⑤ Sulfur dioxide leaves the system.

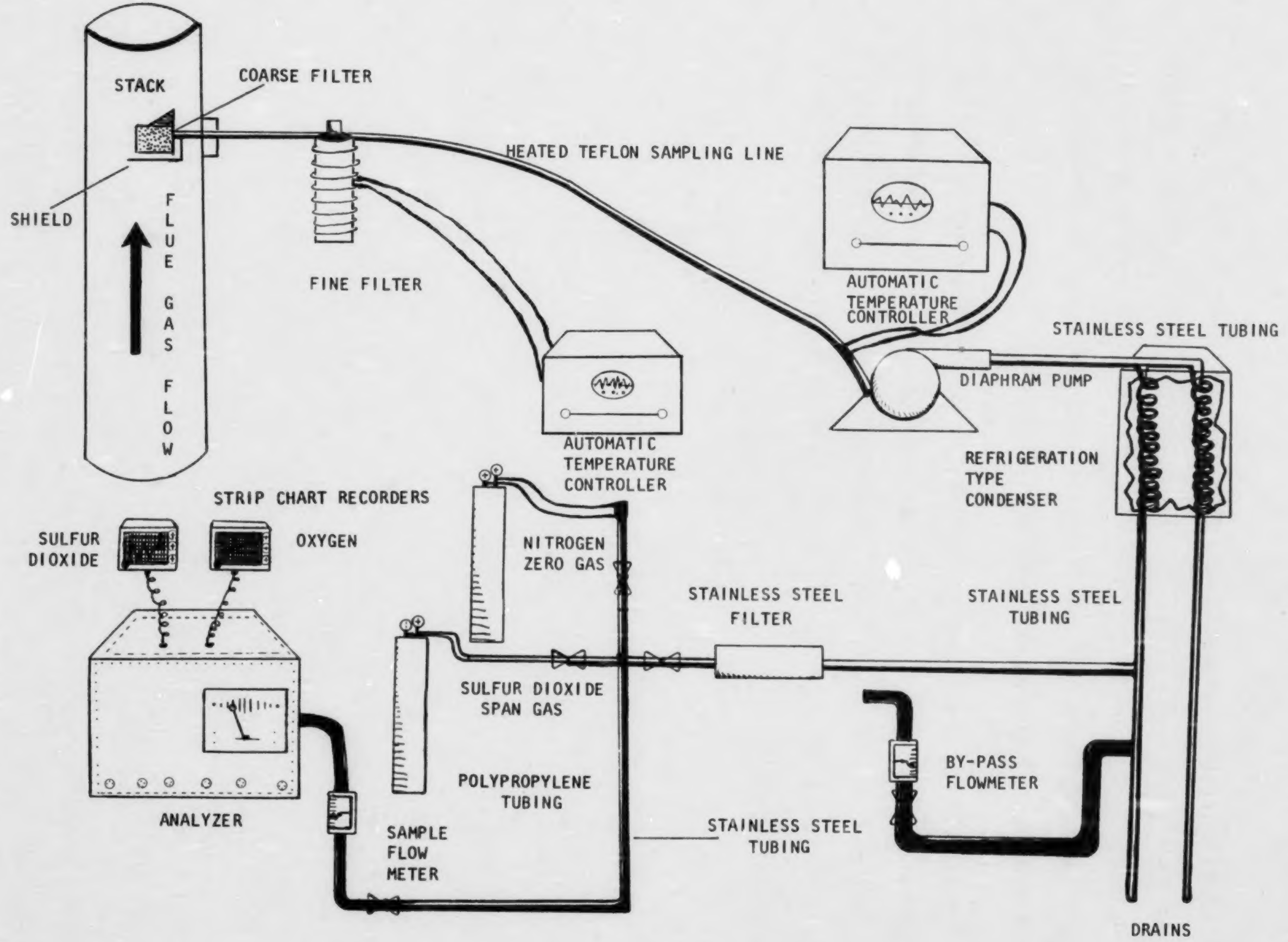

STACK
COARSE FILTER
SHIELD
FLUE GAS FLOW
FINE FILTER
HEATED TEFLON SAMPLING LINE
AUTOMATIC TEMPERATURE CONTROLLER
AUTOMATIC TEMPERATURE CONTROLLER
STAINLESS STEEL TUBING
DIAPHRAM PUMP
REFRIGERATION TYPE CONDENSER
STRIP CHART RECORDERS
SULFUR DIOXIDE
OXYGEN
NITROGEN ZERO GAS
STAINLESS STEEL FILTER
STAINLESS STEEL TUBING
SULFUR DIOXIDE SPAN GAS
POLYPROPYLENE TUBING
BY-PASS FLOWMETER
ANALYZER
SAMPLE FLOW METER
STAINLESS STEEL TUBING
DRAINS

FIGURE 10 Flow diagram of an in-stack continuous SO_2 monitor.

The volume of exhaust gases was another parameter necessary in the analysis of the power plants. Basically, the flue gas flow was determined as a function of the steam load of the boiler. That is, the steam load provided an indication of the coal firing rate, which together with the excess air measurements, could be used to determine the volume of flue gas.

In conjunction with the volume of flue gas, it was also necessary to know the temperature at which the flue gas was emitted. This temperature was either measured directly, or, lacking that, determined on the basis of steam load and boiler design data. Normally, higher steam loads resulted in higher exhaust gas temperatures.

METEOROLOGICAL DATA

The most complex portion of the SO_2 study involved the collection, verification, and utilization of the meteorological data necessary for the precise application of the diffusion model. The meteorological parameters are necessary to determine the rise of the plume, as well as how it spreads (diffuses) in both the vertical and horizontal directions. This section of the report deals basically with the collection of the meteorological data used in determining the diffusion model variables. Their application to the actual model is discussed later.

Because of the complexity of the task and the manpower and expertise required, DEQ contracted with the Department of Climatology and Meteorology, Iowa State University, Ames, Iowa, to perform most of the data gathering and analysis required to obtain the necessary meteorological variables. Unless otherwise indicated, the discussion which follows relates to the work that department has performed.

"Hot air rises" is a basic observation of physics. Yet the rate at which the hot plumes from the power plant stacks rise depends upon the difference between the plume temperature and the ambient air temperature. Ambient air temperature measurements were recorded at the Atomic Energy Commission (AEC), Ames Laboratory Research Reactor Meteorological Tower, Ames, Iowa, at four different heights up to 16 meters. These four temperature readings could then be applied, using appropriate formulas, to calculate a vertical temperature profile and predict the ambient air temperature at stack height and at the total height of the plume-rise. The vertical temperature profile would indicate the lapse rate of temperature, or more simply put the change of temperature with height.

Naturally, the wind direction must be known to indicate whether the wind carries the plumes toward the ambient air monitors and also to determine the relative location of the centerline of the plume as it travels downwind. DEQ employed one wind direction indicator atop each of two air monitoring trailers; those at Sites 1 and 8 in Ames, and Sites 1 and 8 in Des Moines. (Refer to maps on Figures 2 and 3 respectively.)

Stability of the atmosphere refers to the degree of vertical mobility and movement of the lower atmosphere. Stability, and its mathematical definitions, play a critical role in application of diffusion modeling. Several methods of determining stability were studied by the ISU staff. These methods required various meteorological parameters, one of which was cloud cover. The degree of cloud cover would indicate the amount of solar radiation reaching the lower atmosphere, therefore its relative temperature, and hence the stability. Cloud cover measurements used were those recorded in Des Moines at the Municipal Airport. These values were reported in eights, e.g. 8/8 representing cloudy skies and 0/8 representing clear skies.

Incoming solar radiation was also determined, or estimated, using two other methods. The first involved the solar altitude or angle of the sun. These angles have previously been determined and are available from the literature. The second method of measuring incoming radiation involves using an Epply pyrheliometer which makes an analog recording of the solar radiation.

Another independent method of determining stability required yet other meteorological variables to be measured. It has long been recognized that the horizontal wind speed increases with height. The magnitude of this variation is governed primarily by the stability of the atmosphere. Therefore, observations of the vertical variation of the time averaged horizontal wind velocity were made. These wind speed measurements were recorded over the last five years at five different levels on the AEC tower, ranging from 2 to 32 meters in height. Application of this vertical wind profile data, using designated formulas, would then provide indications of diurnal and seasonal behavior of stability.

In conjunction with the stability determination, the fluctuations of the horizontal wind direction would directly affect the horizontal spreading, or diffusion, of the plume. This deviation of the wind direction was measured at the 16 meter level of the AEC tower. From the values of these measurements, empirical equations are used to transform them into vertical variations of the horizontal wind direction, and therefore the relative stability of the lower atmosphere.

SELECTED TIME PERIODS FOR ANALYSIS

For each of the two portions of the Sulfur Dioxide Study, approximately 2,160 hours of data was available. This volume of data was later reduced through a process of selecting specific time periods when all instruments were operational and conditions were such as to enable accurate diffusion model calibration.

Tables 4 and 5 show these specific time periods selected for the Ames and Des Moines portions of the study respectively. The time periods shown were selected primarily on the basis of wind direction. They correspond to the times when the wind prevailed from the northwest direction and when the wind direction did not fluctuate greatly. The number of hours in the time periods listed for the Ames study are less than for the Des Moines portion, because the ambient air monitoring data for November, 1974, was considered suspect due to calibration problems with the air monitoring equipment. The total number of hours selected for further analysis was 264 for Ames and 882 for Des Moines. DEQ was later forced to further reduce the number of hours for subsequent analysis.

TABLE 4

TIME PERIODS FOR ANALYSIS

AMES SO_2 STUDY

Date	TIME PERIODS	
	From	To
12-11-74	1600	2400
12-12-74	0000	0900
12-20-74	1800	2400
12-21-74	0000	1000
12-23-74	2000	2400
12-24-74	0000	0800
12-29-74	0900	2400
12-30-74	0000	2100
1-1-74	0000	1900
1-3-75	0500	1700
1-7-75	0200	1000
1-8-75	0600	1600
1-18-75	2100	2400
1-19-75	0000	2000
1-19-75	2200	2300
1-21-75	0200	0600
1-21-75	1000	2400
1-22-75	0000	0900
1-25-75	0300	2300
1-26-75	0000	1800
1-27-75	1000	2400
1-28-75	0000	0300
1-29-75	0100	1900
1-30-75	2200	2400
1-31-75	0000	0800

TABLE 5

TIME PERIODS FOR ANALYSIS

DES MOINES SO_2 STUDY

Date	TIME PERIODS From	To
2-4-75	1500	2400
2-5-75	0000	2400
2-6-75	0000	2100
2-7-75	1200	2400
2-8-75	0000	2400
2-9-75	0000	0600
2-10-75	2200	2400
2-11-75	0000	0600
2-11-75	1100	2400
2-12-75	0000	2400
2-13-75	0000	0200
2-15-75	0400	1400
2-18-75	1000	2400
2-19-75	0000	0300
2-21-75	1500	2400
2-22-75	0000	2400
2-23-75	0000	2400
2-24-75	0000	2400
2-25-75	0000	2400
2-26-75	0000	2300
2-27-75	0200	2400
2-28-75	0000	2400
3-1-75	0000	2400
3-2-75	0000	2400
3-3-75	0000	2400
3-4-75	0000	0100
3-5-75	1400	2400
3-6-75	0000	0400
3-6-75	2000	2400
3-7-75	0000	2400
3-8-75	0000	1800
3-12-75	0000	2400
3-13-75	0000	1100
3-13-75	2200	2400
3-14-75	0000	0500
3-18-75	1000	2300
3-19-75	2000	2400
3-20-75	0000	0700
3-21-75	0600	2400
3-22-75	0000	1400
3-24-75	0800	2300
3-25-75	1500	2100
3-28-75	1200	2400
3-29-75	0000	2400
3-30-75	0000	1600
3-31-75	0900	2400
4-1-75	0000	2400

TABLE 5 (CONTINUED)

TIME PERIODS FOR ANALYSIS (Continued)

DES MOINES SO_2 STUDY

Date	TIME PERIODS	
	From	To
4-2-75	0000	2400
4-3-75	0000	2200
4-10-75	0200	2400
4-11-75	0000	2400
4-12-75	0000	2000
4-17-75	1600	2400
4-18-75	0000	2400
4-19-75	0000	2400
4-20-75	0000	1700
4-30-75	1000	2000

ATMOSPHERIC STABILITY

The Department of Climatology and Meteorology at Iowa State University was responsible for the determination of atmospheric characteristics representative of central Iowa. From the meteorological data recorded, it was possible to estimate the stability of the atmosphere using several well-known methods. Upon analysis of these results, the stability could then be defined reliably in terms of readily available meteorological data.

One of the methods used in establishing stability was that proposed by Turner[3]. This method involves a minimum of atmospheric variables as input parameters. Turner defines stability based on the solar altitude and the amount of cloud cover; therefore providing an indication of the vertical mixing due to solar heat flux. The solar altitude as a function of the time of day and day of year are currently available for Iowa from Engel and Takle[4]. This data together with the hourly cloud cover observations and horizontal wind speed at 8 meters can be used to determine stability.

A second independent method of calculating stability is by observing the vertical variation of the horizontal wind speed. The increase in horizontal wind speed with height can be used to indicate the stability by observing the magnitude of this variation. The power law profile[5] states that

$$\frac{V_2}{V_1} = \left(\frac{Z_2}{Z_1}\right)^{\beta}$$

where Z_1 and Z_2 are different heights above the earth's surface and V_1 and V_2 are the horizontal wind velocities at these respective heights. β is some number between 0 and 1 whose magnitude depends on the atmospheric stability.

Once the heights and their respective wind speeds are known, β can be determined. Calculations of β have been made based on data collected in past years at the AEC Ames Lab Research Reactor meteorological tower (See Appendix C). Plots of the calculated β have been made and show the diurnal and seasonal variation. β ranges from about 0.13 (most unstable) to about 0.8 (very stable).

A comparison of the results obtained from the two methods of calculating stability, as described above, showed that both methods predicted the same relative magnitude of vertical mixing in the atmosphere. Because of the good correlation between the two methods, the ease of defining the stability, and the standard meteorological data required, the Turner model was selected for use in classifying stability. However, as suggested by other researchers in the area (Shir and Shich, 1974)[6], the stability was defined as a continuous variable; thus allowing for any transition periods between stability classes. Table 6 sets forth the resulting stability classifications. Note that the only parameters necessary to determine a stability number are the degree of incoming solar radiation, wind speed measured at a height of 8 meters, the time of day, and the degree of cloud cover. All are easily obtainable parameters. Also note that, as mentioned, the stability numbers are considered continuous variables; therefore, linear interpolation can be used to define a stability number between the indicated wind speeds. Table 7 on the same page provides a cross-index between the resulting stability numbers used in this study and the well-known Pasquill stability categories[7].

Henceforth, throughout the report, the stability number will be used for all equations and all model calibrations.

TABLE 6

MATRIX USED TO DETERMINE STABILITY CLASS VALUES*

8m wind speed ($m\ sec^{-1}$)	DAY			TRANSITION		NIGHT	
	Incoming Solar Radiation					Clouds	
	Strong	Moderate	Weak	Day/Night	Night/Day	$>4/8$	$<4/8$
0-2	-3.5 to -3.0	-3.0 to -2.2	-2.5 to -2.0	-1.5 to -0.5	1.5 to 0.5	1.6 to 1.5	2.6 to 2.5
2-3	-3.0 to -2.2	-2.2 to -2.0	-2.0 to -1.0	-1.0 to -0.3	1.0 to 0.5	1.5 to 0.6	2.5 to 1.6
3-5	-2.2 to -1.5	-2.0 to -1.0	-1.0 to -0.5	-0.6 to -0.2	0.5 to 0.3	0.6 to 0.3	1.6 to 0.5
5-6	-1.5 to -1.0	-1.0 to -0.3	-0.5 to -0.2	-0.3 to -0.1	0.4 to 0.2	0.3 to 0.1	0.5 to 0.3
6-8	-1.0 to -0.3	-0.3 to -0.1	-0.2 to 0.0	-0.2 to 0.0	0.2 to 0.0	0.1 to 0.0	0.3 to 0.1
8	-0.3	-0.1	0.0	0.0	0.0	0.0	0.1

*See Turner (1969) for complete explanation

TABLE 7

KEY TO STABILITY CLASSES

Pasguill Stability Category		Stability Number
A	Very Unstable	<-2.5
B	Unstable	-2.5 to -1.5
C	Slightly Unstable	-1.5 to -0.5
D	Neutral	-0.5 to +0.5
E	Slightly Stable	+0.5 to +1.5
F	Stable	$>+1.5$

EFFECTIVE STACK HEIGHT TEMPERATURE

Effective stack height temperature (ESHT) is the ambient temperature of the atmosphere at the height at which the plume travels. This height corresponds to the stack height plus the height of the plume rise. The ESHT is used in the Gaussian diffusion model to indicate the relative rise of the plume because of any temperature difference between the plume and the ambient air.

The method for establishing the equation used to predict temperature changes with height (also defined as temperature gradient) was based on data gathered from the AEC tower at Ames. As mentioned previously, the change in temperature with height is a function of stability; therefore, the equations defining temperature gradients are classified on the basis of the previously determined stability number.

The resulting equations derived from the study are:

Stability Category	Stability Number	Equation
stable	$> +0.5$	$T_a = T_{2m}$
neutral	$+0.5$ to -0.5	$T_a = T_{2m} - 0.0098(H-2+\Delta H)$
unstable	< -0.5	$T_a = T_{2m} - 0.013(H-2+\Delta H)$ if plume rise is 100 meters or less or - $T_a = T_{2m} - 1.27-0.0098(H+\Delta H-100)$ if plume rise is greater than 100 meters.

where T_a is the calculated ESHT in ^{o}C, T_{2m} is the observed temperature at the 2 meter height in ^{o}C, H is the stack height in meters, and ΔH is the plume rise in meters.

At first glance, it would appear that the only method of determining the ambient temperature at plume height would be to first know the plume rise, yet the plume rise equations considered rely on the ambient temperature in their calculations. The expression commonly used in plume rise equations is $\left(\frac{Ts-Ta}{Ts}\right)^{1/3}$ where Ts is the stack temperature. A sensitivity analysis of the effect of changes in Ta upon the resultant changes in plume rise, ΔH, indicate that ΔH is very insensitive to incremental changes in Ta. Therefore, plume rise, for use in ESHT equations, may be approximated by using the 2 meter temperature in the plume rise equation. The resulting ΔH may then be used in the ESHT equations, allowing a more accurate approximation of T_a at the plume rise height. This new T_a can then be applied to the plume rise equations to obtain the final ΔH. Actually, if this is iterated several times; one can arrive at fairly constant values of T_a and ΔH.

As evident from the discussion, the only necessary item of meteorological data required to establish a temperature profile is to know the ambient temperature at a height of 2 meters.

WIND VELOCITY PROFILE

As mentioned before, in the establishment of stability characteristics of the atmosphere, a power law relationship provided an indication of the variation of wind speed with height. The power law used the exponent β, which depended on the stability.

From data gathered in the past, the hourly variation of β has been established. Figures 11 and 12 of Appendix C show the power law exponent as a function of the time of day. By knowing β, one can easily apply the power law equation to obtain wind velocities at various heights, knowing a given wind speed and height.

This wind velocity profile is utilized in two portions of diffusion modeling applications. First, the plume rise formulas require the wind speed at stack height. Knowing the 8 meter wind speed (used in determining stability numbers) and the stack height, one can calculate the wind speed at that stack height. This wind speed can then be utilized in the appropriate plume rise formula to calculate plume rise. The plume rise can be added to stack height to give effective stack height. In the Gaussion diffusion model, the wind speed used is that calculated at effective stack height. Therefore, the power law equation is again applied. Knowing the 8 meter wind speed and having determined the effective stack height, one can determine β and hence the wind speed at the effective stack height.

Here, as in the determintion of effective stack height temperature, the amount of meteorological data required is minimal. Use of the graphs in Figures 11 and 12 of Appendix C requires only the time of day and the 8 meter wind speed.

SIGMA Y AND SIGMA Z

A fundamental concept of diffusion modeling is the assumption that the spread of particles in a plume in the horizontal and vertical directions follow a normal or Gaussian distribution. A plot of concentration vs distance around the centerline of a plume would result in a bell-shaped, or normal curve in the vertical and horizontal directions. Cramer (1957)[8] derived a diffusion equation incorporating standard deviations of Gaussian distributions. Sigma y(σy) represents the standard deviation of the distribution of the material in the plume in the crosswind direction. Sigma z(σz) is the standard deviation for the vertical distribution of the material in the plume. The larger sigma y and sigma z are the more pronounced the spread of material in the plume. The more unstable the atmosphere, the larger sigma y and sigma z become. Thus, by defining values of σy and σz and applying them in a diffusion equation, one can predict the relative spread of the plume and the effect that the spread will have on the concentration of material within the plume.

In order to calibrate a diffusion model, sigma y and sigma z must be defined for the existing meteorological conditions. Since sigma z indicates the relative spread of the plume in the vertical direction, the photographs taken of the power plant plume could be used to provide a visual method of determining the spread of the plume with respect to downwind distance. The use of this technique relies on the assumption that the visual outline of the plume corresponds to the loci of points having a concentration of material one-tenth that at the centerline of the plume[3]. This then would allow the use of the Gaussian distribution of plume concentration. Having established this, the plume width is then defined as 4.3 times σz[3]. By visually determining the width of the plume, one can divide by 4.3, obtain a "observed" σ_z and compare this with a "calculated" σ_z using other techniques. The correlation between the measured and calculated would then provide a correction to be applied to the diffusion model equation.

As explained in the section regarding the photographic system, readings were taken from 10 frames of photos for every hour of the selected hours. From this data, which was manipulated by computer, the average width of the plume was calculated for various downwind distances. The computer program then determined the appropriate σ_z values for the downwind distance and catagorized this information for the various stability numbers observed, and thus provided the "observed" σ_z's.

The meteorological data section mentioned the measurement of the variation of the horizontal wind direction. This corresponds to the measurement of the azimuth angle, a. The standard deviation of this angle, σ_a, is estimated by taking one-sixth of the range, in degrees, of the 16 meter wind direction over a one-hour period. Based on relationships given in ASME (1973)[9] this value can be related to the standard deviation of the elevation angle, σ_e. From additional equations given in ASME (1973), sigma y and sigma z values can be calculated for the various heights and downwind distances. (A full explanation of the equations used is presented in Appendix C, and therefore will not be repeated here).

Another method of determining σ_y and σ_z is that used by Turner (1969). Turner's curves, based on Pasquill's stability categories, are shown in terms of discrete stability indexes. Since the stability numbers chosen for the study are continuous variables, interpolation between Turner's curves is possible. This allowed the determination of σ_y and σ_z for all values of stability and downwind distances. The charts shown in Figures 11 and 12, though based on Turner's charts, are drawn in terms of stability numbers. As mentioned, intermediate values are established by linear interpolation.

The observed meteorological data did not permit the verification of the calculated sigma y. It is felt that the lack of verification of the calculated sigma y will not jeopardize the calibration of the diffusion model, since visual observation of the plumes indicate insignificant variations in crosswind diffusion of the plume, and therefore fairly consistent values of sigma y.

A comparison of the observed $^{\sigma}z$ and the $^{\sigma}z$'s calculated using Turner's and the ASME method, showed good correlation. Though the observed values differed somewhat from the various calculated values, the variance from both methods appeared consistent, indicating that either method was equally in error. Therefore, based on this premise and the fact that Turner's method involves less data, the ratios of calculated (Turner's method) to observed (photo data) were used in subsequent analysis. This ratio was then plotted versus stability number to provide a correlation factor for various stability conditions. Thus, knowing the stability number, one could use the modified Turner charts (Figures 11 and 12) to find a calculated sigma z and sigma y and divide this by the ratio of calculated to observed to provide the actual sigma z.

The sigma y read from the Turner charts is assumed to provide a valid indication of the horizontal spread of the plume without the application of any correction factors.

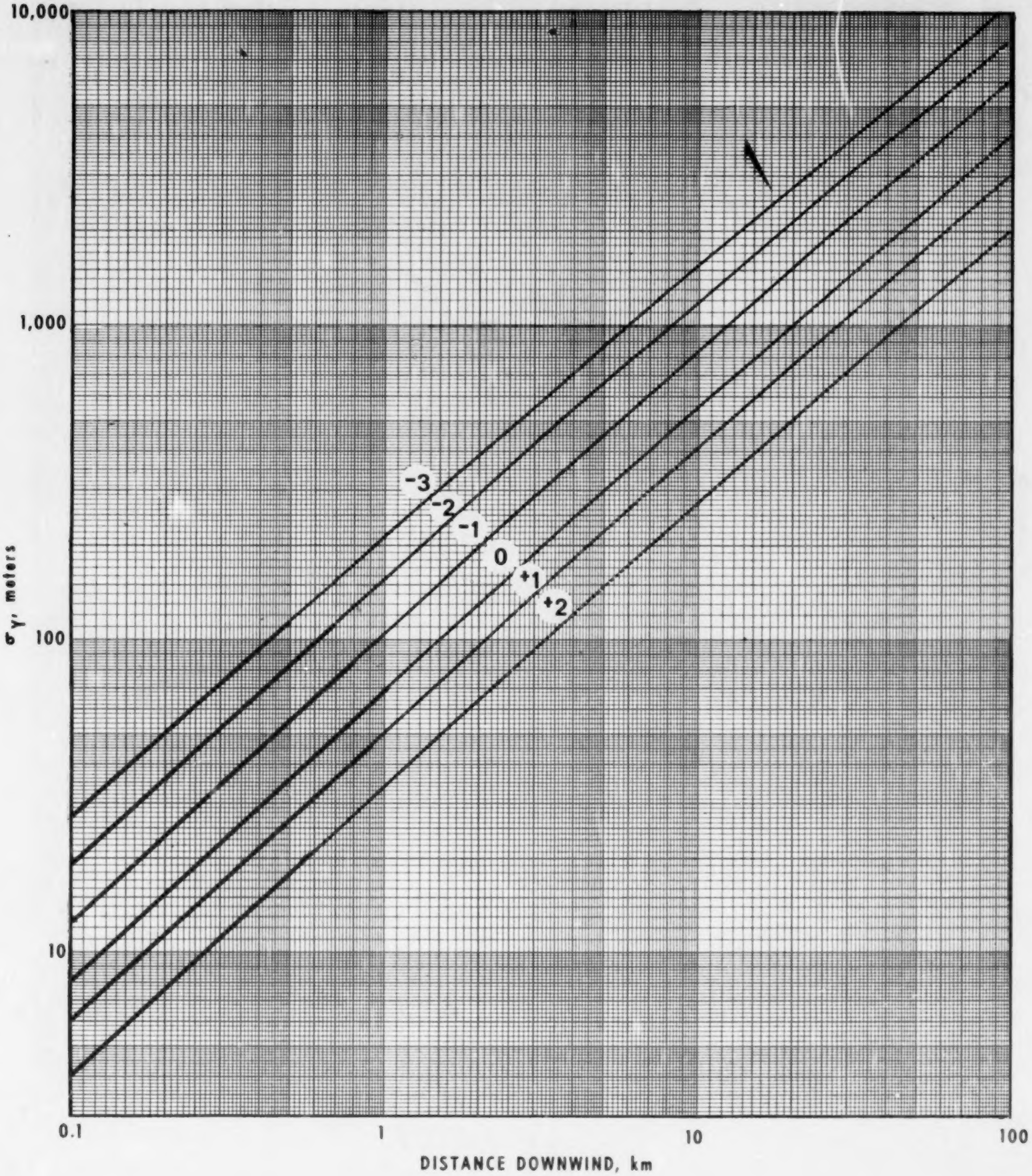


FIGURE 11 Horizontal dispersion coefficient as a function of downwind distance from the source.

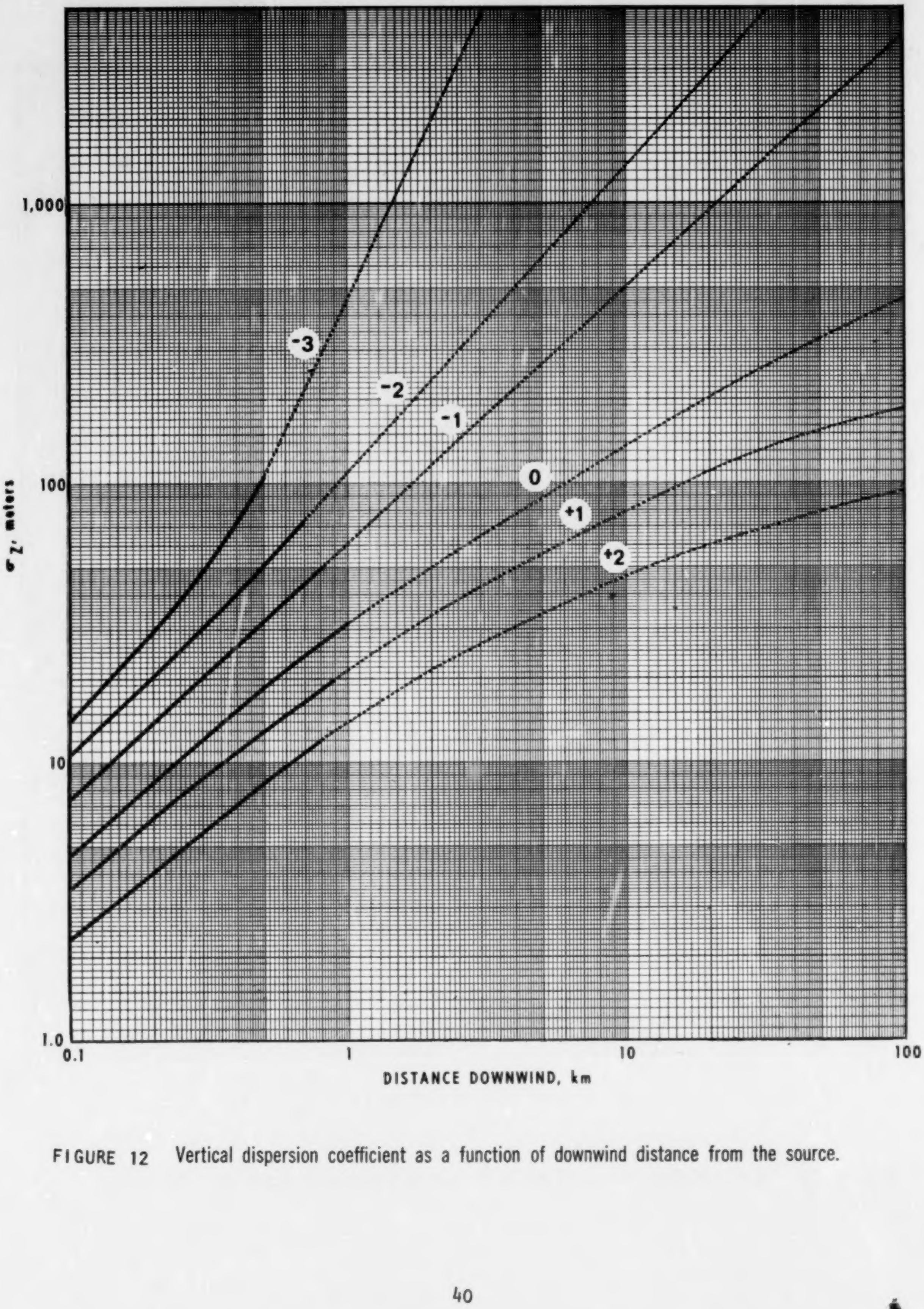


FIGURE 12 Vertical dispersion coefficient as a function of downwind distance from the source.

PLUME RISE EQUATION

Besides allowing the determination of sigma z values, the analysis of the photographic data also revealed the relative plume rise of the effluents from the power plant stacks. Through the use of various computer techniques, the plume rise, relative to the top of the stacks, was determined for the various downwind distances measured from the photos. The plume rise, ΔH, was then utilized in the commonly used Briggs' plume rise formula.[10] The following formula was used for analysis:

$$\Delta H = \frac{1.6 * F^{1/3} * x^{2/3}}{u^{1/3}} \qquad (1)$$

where x represents the downwind distance in meters, u the mean wind speed in meters per second, and F represents the buoyancy flux of plume in meters^4 per seconds cubed. The flux, according to Briggs', can also be represented by:

$$F = 3.12 * V_F * \left(\frac{T_s - T_a}{T_s}\right) \qquad (2)$$

where V_F is the exhaust flow from the stack in cubic meters per second, T_s is the stack gas temperature in degrees Kelvin, and T_a is the ambient temperature in degrees Kelvin.

In the evaluation of these plume rise formulas, the observed ΔH, along with the known downwind distance and wind speed, allowed the calculation of the flux, F, termed the buoyancy flux parameter.

The flux, F, was also calculated for the same time periods using equation (2), based on the observed power plant stack parameters. The two calculated fluxes were then compared to see if a possible correlation existed.

Based on the comparisons conducted to date, it appears that no correlation exists between the fluxes calculated using the two equations. An evaluation of the comparative values indicates at this time, that the Briggs' plume rise formula is inappropriate for the conditions observed during this study. Therefore, as a future project, DEQ should perform more detailed analyses of the plume rise equations currently in existence. If an appropriate correlation cannot be established using well-known plume rise calculations, an indpendent plume rise equation may have to be developed to specifically represent the conditions observed in central Iowa.

The available plume rise values observed from the photos can be used in the calibration of the Gaussian model for the specific time periods of the study. However, since such data is not normally available, DEQ should proceed with the analysis of plume rise equations. The culmination of these evaluations should permit the determination of a generally applicable formula for use in a calibrated Gaussian model.

CALIBRATION OF THE GAUSSIAN MODEL

As stated in the introduction, one of the purposes of this study is to calibrate the Gaussian diffusion model equation. The equation typically used appears below Figure 13. Because of the lack of verification of a plume rise formula the model has not yet been evaluated in the conventional manner as proposed, but has been evaluated with a special statistical/diffusion modeling approach which is outlined in the summary. However, the methods for performing the conventional verification of this equation have been outlined. First, though, an explanation of the terms of the equation is in order.

χ = the expected 10-minute to one-hour ground level concentration at the point x, y, z on the coordinate system shown in Figure 13.

Q = the SO_2 emission rate, in grams per second.

u = the mean wind speed at expected plume rise, in meters per second.

σ_y = the standard deviation of the concentration of material in the crosswind, y, direction, in meters.

σ_z = the standard deviation of the concentration of material in the vertical, z, direction, in meters.

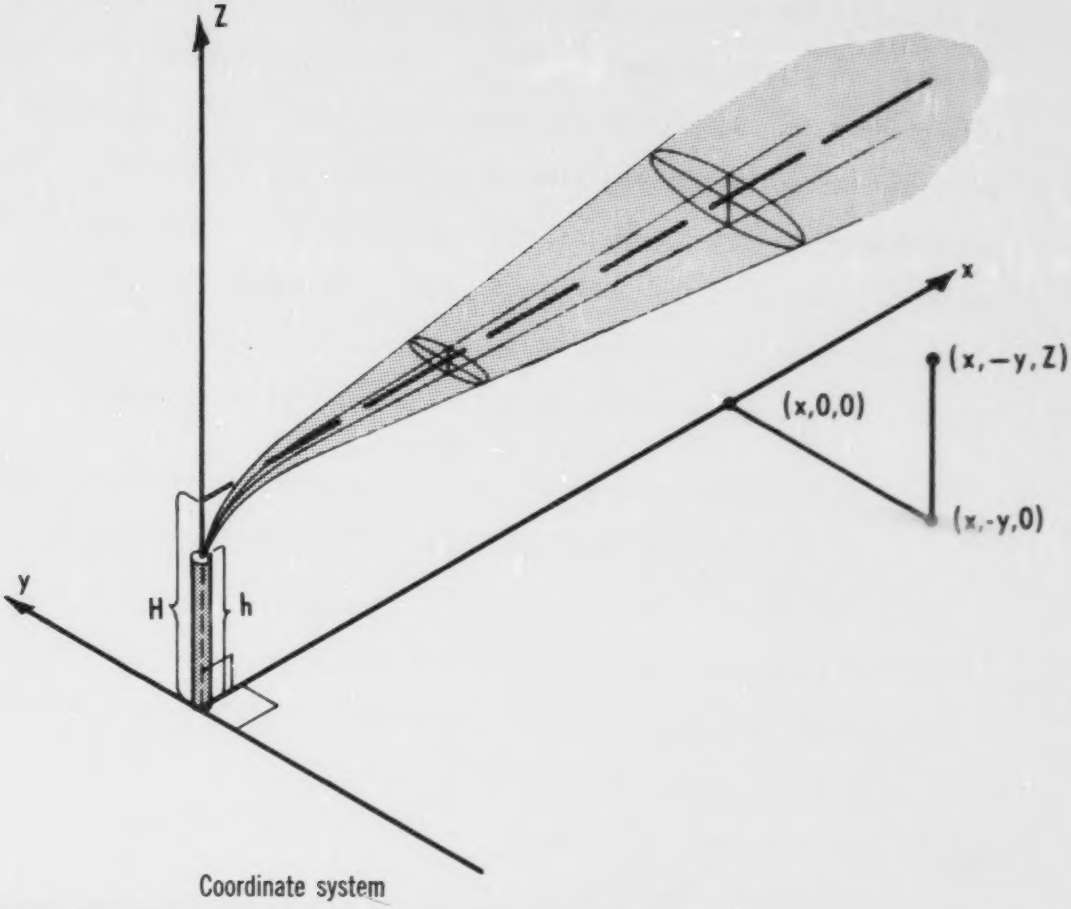
y = the crosswind distance from the centerline of the plume to the receptor, in meters.

x = the downwind distance from the source to the receptor, in meters.

z = the height of the receptor above the base of the source stack, in meters.

H = the plume height at the downwind distance x, in meters. H therefore equals the height of the source, h, plus the plume rise, ΔH.

Note that in the Gaussian equation, "exp" refers to e (equal to 2.71828) raised to the power of the terms in parenthesis.


Z
x
(x,−y,Z)
(x,0,0)
(x,-y,0)
y
H
h
Coordinate system

$$\chi\,(x,y,z;H) = \frac{Q}{2\pi\,\sigma_y\,\sigma_z\,u}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$
$$\left\{\exp\left[-\frac{1}{2}\left(\frac{z\text{-}H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\}$$

FIGURE 13 "GAUSSIAN DIFFUSION MODEL"

In the calibration of the Gaussian equation, the various parameters obtained throughout the study will be applied to the formula to obtain a calculated value of ground level concentration at the sites of the various ambient air monitors. These calculated values will then be compared to the observed concentrations for the same time periods. This comparison of results should allow the determination of a correction factor which could then be applied to subsequent diffusion modeling studies to hopefully accurately predict expected downwind ground level concentrations. If appropriate correction factors show a low degree of correlation, the diffusion model itself may be inappropriate and therefore require more extensive analysis to develop a specialized form of the Gaussian equation which could be applied to emission sources in Iowa.

POWER PLANT STACK PARAMETERS

After acquiring the necessary power plant data, calculations were made to determine the three essential parameters for each stack involved in the study. The parameters calculated are those required as input for the Gaussian diffusion model. These parameters are: 1) the stack flue gas flow, 2) the stack gas temperature, and 3) the concentration of sulfur dioxide emitted. The calculations performed to obtain these parameters involved coal sampling data, boiler operating data, boiler design characteristics, and in-stack SO_2 monitoring results.

From the units at Ames, Iowa, Table 8 represents the design parameters utilized in the determination of boiler data not readily obtainable from measured variables. Intermediate values on the table are determined using linear interpolation, based on the observed steam load. Having these values, the following calculations were performed.

$$B=(H-W) * S/E \qquad (1)$$

where B = gross BTU/HR heat input

H = enthalpy of steam, BTU/pound

W = enthalpy of feed water, BTU/pound

S = steam load, 1000 pounds/hour

E = thermal efficiency of boiler

$$C=G*4083 \qquad (2)$$

where C = BTU/HR from natural gas usage

G = gas integrator reading

and the constant (4083) represents the gas integrator coefficient, the heating value of the gas, and the conversion to an hourly basis.

TABLE 8

IOWA STATE UNIVERSITY

BOILER PARAMETERS
AMES, IOWA

Unit No.	Steam ($1000^{\#}$/HR)	Boiler Efficiency (%)	SO_2 Conversion (%)	Flue Gas ($^{\#}$/HR)	Stack Temp. (^{o}F)
1 & 2	40	77	95	62,500	305
	80	79	95	117,000	340
	100	78	95	147,000	370
	120	76	95	179,500	420
3	60	80	96	105,900	325
	140	80	96	222,000	380
	150	81	96	228,600	390
5	60	79	95	96,800	358
	135	81	95	180,000	385
	150	82	95	190,000	396
6	40	77	95	60,300	395
	80	79	95	113,200	405
	120	76	95	165,700	483

Heating value of coal, BTU/pound, wet basis = $N*(1-\frac{M}{L})$ (3)

Percent sulfur, wet basis = $S*(1-\frac{M}{L})$ (4)

where N = heating value of coal, BTU/pound, dry basis, from coal sampling data.

M = moisture removed from coal sample, grams

L = beginning weight of coal sample, grams

S = percent sulfur, dry basis, from coal sampling data.

$D=B-C$ (5)

where D = net BTU/HR from coal combustion

Equation (5) results from the fact that negligible sulfur dioxide, if any, is emitted from the combustion of natural gas.

The SO_2 emission rate is therefore determined by the formula -

$$\frac{D*(\text{Percent sulfur, wet basis}) * (2\#SO_2/\#S) * K}{(\text{Heating Value, BTU/\#, wet basis}) * 10{,}000} \qquad (6)$$

where K = SO_2 conversion rate. Equation (6) results in the emission rate of SO_2 in pounds/hour.

The stack temperature for each unit is determined from Table 8. Also, the volume of flue gas is similarly obtained.

The physical plant at Ames is constructed such that Units No. 1, 2, & 3 utilize a common stack, referred to as the tall stack, or Stack #1. Units No. 5 and 6 also discharge through a common stack, referred to as the short stack, or Stack #2. Therefore, the stack parameters for the two stacks were based on the weighted average of the corresponding parameters from the units serving the stacks.

The analysis of the data obtained from the Des Moines power plant proceeded in a similar manner. The coal sampling results were treated the same as those for Ames thereby providing the heating value (BTU/pound), the percent sulfur, the percent ash, and the percent moisture, all on an "as-received" basis.

The stack temperature for Units 10 and 11 in Des Moines was obtained directly from a temperature recorder for each stack.

Though the calculated parameters for input into the diffusion model remained the same for Des Moines as for Ames, the methods of their calculation differed. The emission rate of SO_2 was determined as follows:

$$SO_2\text{, grams/second} = \frac{U*S*K*C*0.1513}{T*B} \tag{7}$$

where U = total BTU input, obtained from recorders

S = percent sulfur, as received

K = SO_2 conversion rate, percent

C = ratio of measured to theoretical flue gas flow, obtained from boiler design parameters.

T = total time in minutes of heat input measurements

B = heating value of coal, BTU/pound, as received

The constant 0.1513 contains the conversion from sulfur to SO_2, minutes to seconds, and pounds to grams.

The volume of flue gas, is calculated using the following:

$$\text{Flue gas, cubic meters/second} = \left[\frac{7.56*B}{10{,}000} * \left(1 + \frac{E}{100}\right) + \left(1 - \frac{A}{100}\right)\right] * \frac{U}{100} * \left(\frac{L + 460}{760}\right) * \frac{0.0090}{T*B} \tag{8}$$

where E = percent excess air, obtained from recorders

A = percent ash in coal, as received

L = stack gas temperature, ^{o}F, obtained from recorder

The above equation (8) calculates the theoretical air emitted from the combustion of a given amount of coal, and using excess air, percent ash, and stack temperature, converts the amount of theoretical air to that actually being emitted.

The SO_2 conversion factor, K, as used in equations (6) and (7), refers to the amount of sulfur that is actually emitted as SO_2. To obtain the values of this factor, DEQ utilized an in-stack SO_2 monitor, which in conjunction with coal sampling data, provided an indication of the K values. By conducting a material balance around the boiler, the conversion rate could be determined. Based on the available data, conversion rates were established for the different types of boilers involved in the study.

As expected, the conversion rates for the different boilers varied. The average K values for the types of boilers were:

Type of Unit	% Conversion, K
Pulverized	99
Traveling Grate	95
Spreader Stoker	96

Unit #3 at Ames was the only spreader stoker unit. Units #1, 2, 5, and 6 at Ames are traveling grates. Both units at Des Moines, #10 and 11, are pulverized units.

Further verification of these conversion rates will be performed as additional calculations are conducted.

FUTURE STUDIES

The vast amount of data generated by the Iowa Sulfur Dioxide Study provides numerous avenues for additional data analysis. Time constraints experienced during the study period itself have prohibited the determination of several useful relationships made available by the data collected.

One of the first studies which DEQ should perform as time permits, is to verify the calculation and evaluation of the power plant data. This evaluation should include additional research on the SO_2 conversion rate experienced in the various types of boilers. This could be accomplished by comparing additional days of in-stack monitoring data with the sulfur firing rate into the boilers. The sulfur firing rate should also be verified by seeking clarification of boiler parameters. The boiler parameters of concern should be those used to determine the exhaust gas flow and the heat input for each of the boilers.

DEQ should also use the available SO_2 air monitoring data to calculate the maximum and second highest 3-hour running average of observed ambient concentrations. These values could then be compared with the corresponding ambient air quality standard.[1]

Time averaging techniques are important both to the interpretation of air monitoring data as well as to the application of diffusion modeling results for differing time periods. DEQ should develop the following time averaging ratios for the ambient SO_2 air monitoring data available: 1) maximum 1-hour concentration to maximum 3-hour concentration, 2) maximum 1-hour concentration to maximum 24-hour concentration, and 3) maximum 10-minute concentration to maximum 1-hour concentration. Calculation of these ratios, for example, would allow a better approximation of the 24-hour concentration based on the the 1-hour concentration predicted by a diffusion model.

Since vast amounts of meteorological data was used to predict and develop stability classifications for this study, it would be useful in the future to have available a frequency distribution of the occurrence of the various stability classifications. This would then provide indications of the relative occurrence of both the worst and best meteorological conditions that could be applied to future diffusion modeling studies.

DATA ANALYSIS

Upon completion of the collection of the various meteorological, power plant, and ambient SO_2 concentration data, appropriate analysis of the data was initiated. Portions of this analysis resulted in the various calculations explained in previous portions of this report. However, further review of various data resulted in summaries of the observed data.

Table 9 presents a summary of the hourly SO_2 concentrations for Sites 1 through 8, the hourly wind speed realized for Site 1 and 8, the hourly wind direction readings for Sites 1 and 8, stability number, effective stack height temperature, and the power plant data consisting of the SO_2 emission rate, exhaust gas temperature, and the volume of flue gas. Table 9 represents the available hourly data for each of the selected hours for the Ames portion of the study. Table 10 presents similar data for the selected hours for the Des Moines portion of the study. Note that concerning the power plant data indicated for the Ames portion (Table 9) Stack #1 refers to the stack serving Units #1, 2, and 3 at Ames. Stack #2 (Table 9) refers to the stack serving Units #5 and 6 at Ames. In Table 10, Stack #1 refers to Unit #10 and Stack #2 refers to Unit #11 at Des Moines. Also note that for many of the selected hours, portions of the indicated data were not presented. For one reason or another, portions of this data were not available; equipment breakdown, calibration periods, or lack of operation data were major reasons for missing data. Data presented for Sites 1 and 8, though presented as hourly, were recorded as ten minute averages then manipulated using computer techniques.[13]

Using the hourly SO_2 concentrations indicated in Table 9 and 10, the 24-hour concentrations were determined, and the summary presented in Table 11 was prepared. Table 11 presents an analysis of the 24-hour concentrations of

SO_2 observed at each of the monitoring sites in Ames and Des Moines. The maximum 24-hour concentrations can be compared with the primary NAAOS for SO_2 of 365 micrograms per cubic meter, maximum 24-hour concentration, not to be exceeded more than once per year. (See Table 1). It is noticed that the maximum 24-hour value recorded at Ames occurred at Site #8 (Refer to Figure 2 for location). This value was recorded on January 19, 1975, which was one of the hours originally selected for analysis (See Table 4). Additional research on the meteorological conditions observed on that day showed that the wind direction ranged from 217 to 324 degrees. The wind speed ranged from 1.5 to 15.9 miles per hour. Diffusion modeling conducted using the above meteorological parameters and the average power plant information indicated that the highest observed value did not result from emissions from the physical plant at Iowa State. No explanation is available at this time for the existence of this highest value.

In reviewing the same 24-hour data presented in Table 11 for the Des Moines portion of the study, the highest value observed was 527.4 micrograms per cubic meter. This value was recorded on March 3, 1975, at Site 4. Referring to Table 10 (since March 3, 1975 was one of the selected hours) the meteorological conditions at that time can be determined. It is noted that the wind direction varied from 185 to 259 degrees. The wind speed ranged from 3.6 to 6.2 miles per hour. By referring to the site location in Figure 3, these meteorological parameters indicate that the recorded values on that date are not directly attributable to the Iowa Power facility. Again, no explanation is currently available for the highest level observed.

In conjunction with the summary of SO_2 monitoring results presented in Table 11, frequency distributions of all observed 24-hour concentrations at the various sites were determined. Figure 14 illustrates the percent relative frequency of the various concentration observed from the monitoring equipment at each of the special sites. The frequency of occurrence is plotted versus the recorded values on the histograms shown.

Using portions of the meteorological data collected at Site 1 and 8 in both Des Moines and Ames, frequency distributions of the wind speed and direction at these sites was generated. Wind speed frequency distributions are presented in the histograms in Figures 15 and 16 for Sites 1 and 8, respectively, in Ames. Figure 17 and 18 present similar data for Sites 1 and 8, respectively, in Des Moines. The wind direction frequency distributions for Sites 1 and 8 in Ames are presented in Figures 19 and 20 respectively. Figures 21 and 22 show the wind direction frequency distribution for Sites 1 and 8, respectively, in Des Moines.

Numerous coal sampling data gathered during this study was also analyzed. Coal samples taken at Ames were categorized based on the type of coal, whether Kansas or Wyoming. Coal sampling data for Des Moines was reported based on the unit being fired with that particular coal, whether Unit 10 or 11. Figures 23 through 30 illustrate the resulting statistical analysis of the coal sampling data. Each figure is labeled to indicate its application. Below each figure the resultant mean, number of samples, and the standard deviation of the samples is presented.

Table 9

TABULATION OF DATA COLLECTED (FOR AMES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (°From North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°K)		VOL. OF FLUE GAS (m^3/sec)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
1974																					
12-11	1700	89	39	0	0	12		3		4.5		329		0.83	2.2	24	14	452	454	28	17
	1800	89	34	0	0	5		0		1.6		354		2.39	1.4	25	12	454	453	30	16
	1900	89	31	0	0	4		0		1.6		344		2.52	0.5	25	13	454	454	30	17
	2000	89	31	0	0	3		0		3.0		337		2.52	-1.3	25	14	455	454	30	17
	2100	89	29	0	0	3		0		1.6		343		2.53	-0.7						
	2200	89	29	0	0	1		0		1.0		346		2.51	-1.1						
	2300	89	29	0	0	1		0		1.6		341		2.52	-1.1						
	2400	89	29	0	0	0		0				388		2.53	-1.0						
12-12	0100	89	26	0	0	1		0				162		2.59	-1.8	80	60	455	485	30	32
	0200	89	26	0	0	0		0				129		2.56	-2.5	77	52	453	460	29	26
	0300	89	26	0	0	0		0				111		2.53	-2.2	56	58	442	478	21	30
	0400	89	26	0	0	0		0				39		2.55	-3.1	56	60	442	485	21	32
	0500	89	26	0	0	0		0				90		2.54	-3.4	59	63	443	477	22	31
	0600	89	26	0	0	0		0				146		2.59	-3.5						
	0700	89	26	0	0	0		0				109		2.59	-4.0						
	0800	89	26	0	0	0		0		1.4		146		2.55	-3.1						
	0900	89	29	0	0	0		0		1.9		160		-0.57	-2.9						
12-20	1900	89	31	0	4	212	5	3	50	6.2	7.3	336	327	0.00	-5.5						
	2000	89	55	0	5	198	8	3	65	3.6	5.2	344	333	0.00	-8.5						
	2100	89	26	0	1	72	3	7	73	4.1	4.9	341	344	0.00	-9.3						
	2200	89	21	0	0	30	0	0		4.8	5.6	333	311	0.00	-9.2						
	2300	89	18	0	0	38		0		2.9	4.7	354	331	1.50	-9.3						
	2400	89	21	0	0	52		0		3.3	4.5	342	312	0.90	-9.0						
12-21	0100	89	18	0	0	27		4		3.8	5.0	335	310	1.51	-9.5						
	0200	89	18	0	0	25		0		3.2	3.9	332	309	1.52	-9.8						
	0300	89	26	0	0	63		0		4.6	4.5	326	256	1.53	-8.2						
	0400	89	18	1	0	29	0	8		4.2	4.1	328	303	0.00	-9.0						
	0500	89	18	12	0	26		0		3.7	3.5	329	301	0.00	-8.7						
	0600	89	18	4	0	26	0	0		3.7	4.0	320	295	0.00	-8.6						
	0700	89	18	0	0	27	0	5		1.3	3.2	349	317	0.00	-8.5						
	0800	89	18	0	0	30	0	5		1.1	1.9	352	314	0.00	-7.4						
	0900	89	18	0	0	39		16		0.6	1.0	348	343	0.00	-7.4						
	1000		24	0	0	34		8		0.6		325	267	0.00	-7.0						

Table 9 (cont)

TABULATION OF DATA COLLECTED (FOR AMES, IOWA)

DATE	TIME	HOURLY SO$_2$ READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO$_2$ EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°K)		VOL. OF FLUE GAS (m3/sec)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
1974																					
12-23	2100	89	29	0	0	26		0	62	6.5	6.4	320	301	2.46	-4.0	78	102	427	476	21	36
	2200	89	26	0	0	25		0	62	6.2	6.7	329	307	2.51	-4.3	64	104	423	481	18	37
	2300	89	24	0	0	20		0	57	7.0	6.2	320	303	1.79	-4.7	68	105	424	483	19	38
	2400	89	24	0	0	21		0	57	7.2	6.7	322	301	2.14	-5.7	78	100	427	472	22	35
12-24	0100	89	24	27	17	20		0	57	5.0	5.7	330	315	2.18	-6.5						
	0200	89	24	25	0	21		0	62	5.9	6.6	329	309	2.25	-7.5						
	0300	89	24	4	0	21		0	57	7.1	6.8	316	301	1.72	-8.2						
	0400	89	24	0	0	22		0	60	5.5	5.0	319	298	2.53	-8.9						
	0500	89	21	0	16	20		0	89	6.7	5.4	313	297	2.53	-8.0						
	0600	89	24	0	13	22		0	86	7.4	6.9	321	300	2.14	-9.2						
	0700	89	21	0	0	20		0	60	6.5	6.7	322	301	1.93	-10.0						
	0800	89	21	0	0	20		4	55	5.1	3.8	300	247	2.52	-10.7						
12-29	1000	89	0	37	0	0	0	0	60	10.6	10.6	311	305	0.00	-0.4	49	109	424	483	19	41
	1100	89	0	539	0	0	0	0	60	10.2	10.0	309	307	0.00	-1.0	49	112	424	490	19	43
	1200	89	16	0	0	0	0	4	60	9.6	9.9	308	306	0.00	-2.8	54	112	426	488	20	42
	1300	89	24	10	0	0	0	5	55	11.4	11.2	308	305	0.00	-2.3	54	112	426	488	20	42
	1400	89	26	30	9	3	0	9	57	11.6	12.3	314	311	-0.60	-1.6	54	112	426	483	20	41
	1500	89	31	33	16	5	0	13	60	10.3	10.9	313	310	-0.53	-1.7	62	108	429	473	23	38
	1600	89	31	35	21	7	0	9	60	10.1	10.5	311	306	0.38	0.5	53	108	426	473	20	38
	1700	89	31	21	17	5	0	12	62	8.9	8.3	309	308	0.45	0.1	53	112	426	483	20	41
	1800	89	31	4	26	4	0	0	60	6.2	6.0	310	307	2.07	-2.8	53	114	426	488	20	43
	1900	89	31	3	26	1	0	0	57	5.6	5.2	303	298	2.53	-3.6	63	111	427	481	22	41
	2000	89	31	1	29	0	0	0	60	5.1	5.1	305	296	2.50	-2.8	63	112	427	483	22	41
	2100	89	29	0	25	0	0	0	55	4.3	4.2	309	294	2.04	-4.4	63	108	427	473	22	38
	2200	89	29	20	0	0	0	0	57	3.1	4.4	314	312	2.49	-4.2	63	107	427	472	22	38
	2300	89	29	0	20	0	0	0	55	3.5	3.6	304	298	2.49	-4.1	63	106	427	473	22	38
	2400	89	29	0	24	0	0	0		2.9	3.4	311	303	2.52	-3.1	63	109	427	481	22	40
12-30	0100	89	29	0	33	0	3	0		3.5	2.0	308	294	2.55	-3.7	24	31	427	462	22	25
	0200	89	26	0	65	0	0	0		1.8	2.0	295	235	2.54	-4.5						
	0300	89	24	0	51	0	3	0			1.3	257	247	2.54	-5.6						
	0400	89	21	0	76	0	0	0			.2	259	301	2.53	-5.3	22	43	427	479	22	40
	0500	89	16	0	65	0	0	0			.2	288	267	2.54	-6.5	7	12	423	508	7	15
	0600	89	16	0	77	0	0	0			.3	277	280	2.52	-7.8	24	41	429	475	23	38
	0700	89	13	0	77	0	0	0			.1	247	251	2.57	-7.6	24	41	429	475	23	38

Table 9 (cont)

TABULATION OF DATA COLLECTED (FOR AMES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°K)		VOL. OF FLUE GAS (m^3/sec)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
1974																					
12-30	0800	89	13	0	76	0	0	0			.3	190	241	2.58	-7.8	24	41	429	475	23	38
	0900	89	16	0	80	0	0	0				266	158	-1.3	-7.3	22	42	427	477	22	39
	1000	89	24	0		0	0	3			.2	278	254	-1.39	-7.0	22	43	427	481	22	40
	1100	89	29	0		0	0	7		1.4	.9	211	335	-2.45	-4.0	22	42	427	472	22	38
	1200	89	34	14		1		8		3.2	2.9	142	136	-2.17	-1.2	22	44	427	475	22	40
	1300	89	39	0		10	0			4.1	3.8	145	147	-1.8	0.3	22	43	427	475	22	39
	1400	89	37	0		10	0	34		4.7	4.8	138	140	-1.49	0.9						
	1500	89	37	0		10	76	34		2.7	2.2	139	120	-1.53	1.1						
	1600	89	37	0		12	18	30		3.0	3.8	129	125	.86	1.0						
	1700	89	29	0		7	0	24		1.5	1.8	141	133	.57	0.9						
	1800	89	24	0		3	0	10		1.6	2.3	142	139	2.52	0.5						
12-30	2000	89	18	0		0	0	7		1.5	2.6	117	106	2.49	-0.4						
	2100	89	24	0		3	18	12		2.8	3.4	125	115	2.14	-0.5						
1-1	0100	89	29	0		26	0	13	57	8.9	10.1	277	275	0.97	-4.9						
	0200	89	31	0		0	0	8	55	9.5	10.3	282	277	0.88	-5.8						
	0300	89	31	0		3	0	10		9.5	10.9	282	279	0.77	-6.4						
	0400	89	34	0		47	0	13		8.6	8.7	271	270	0.82	-6.5						
	0500	89	34	0		48	0	5		7.7	7.9	274	273	0.63	-7.0						
	0600	89	37	0		42	0	9		7.1	7.3	271	262	0.95	-7.1						
	0700	89	37	0		0	0	17		8.5	8.1	262	255	0.71	-6.9						
	0800	89	39	0		0	0	17		8.4	9.9	258	254	0.63	-6.7						
	0900	89	39	0		22	0	20		8.8	9.2	269	264	-0.24	-5.6						
	1000	89						21		9.5	9.6	272	270	-0.36	-3.8						
	1100	89	39	0		86	0	21		11.2	11.5	274	273	-0.60	-2.0						
	1200	89	39	0		43	0	22	65	10.8	11.8	283	279	-0.44	-1.1						
	1300	89	42	0		46	0	27	62	9.1	9.5	272	268	-0.63	-0.3						
	1400	89	44	0		12	0	29	47	8.7	7.8	288	285	-0.85	1.1						
	1500	89	44	1		12	0	24	68	6.9	7.7	279	283	-0.96	1.6						
	1600	89	50	0		9	0	30	60	5.0	4.6	276	262	-0.15	1.9						
	1700	89	47	3		5	0	18	52		1.5	263	258	0.54	1.5						
	1800	89	29	0			0	0			.2	161	196	2.58	-0.3						
	1900	89	21	0		5	0	0		.7	.7	136	143	2.59	-1.4						

Table 9 (cont)

TABULATION OF DATA COLLECTED (FOR AMES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (°from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°K)		VEL. OF FLUE GAS (m/sec)	
		#1	#2	#3	#4	#5	#6	#7	#9	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
1975																					
1-3	0600	89	50	3	7		0	16	65	11.3	12.5	265	257	0.00	-2.9						
	0700	89	45	8	22				70	13.4	14.4	283	279	0.00	-3.5						
	0800	89							65	11.1	12.6	279	279	0.00	-4.0						
	0900	89	52	5	18		0	24	70	11.6	12.2	269	264	0.00	-3.2						
	1000	89	47	10	33		0	26	65	13.8	15.0	273	271	0.00	-2.4						
	1100	89	86	16	41		0	26	57	14.9	16.9	274	276	-0.07	-3.0						
	1200	89	42	33	37		0	29	70	11.1	12.5	266	260	-0.39	-1.9						
	1300	89	47	46	24		0	7	81	12.7	13.3	267	264	-0.13	-2.0						
	1400	89	29	33	51		0	14	75	12.6	12.3	270	260	-0.10	-2.4						
	1500	89	42	35	56		0	16	70	12.6	13.3	273	271	-0.26	-2.6						
	1600	89	31	26	73		0	17	73	10.2	11.6	275	269	-0.46	-2.6						
	1700	89	31	21	73		0	22	68	8.1	9.7	275	268	0.37	-3.6						
1-7	0300	89		0		16		31	60	4.3	4.5	319	294	2.52	-9.2						
	0400	89		0		13		22	60	3.1	3.3	301	292	2.07	-9.4						
	0500	89		0		9		18	57	1.1	2.2	220	214	2.54	-10.6						
	0600	89				7		12	52	1.1	1.3	182	243	2.55	-10.5						
	0700	89				0		13		1.6	1.3	135	184	2.58	-10.8						
	0800	94						7		1.3	1.3	175	75	2.55	-11.2						
	0900	89						12		.9	.9	204	281	-1.20	-10.7						
	1000	89						10	60	1.1	.7	175	242	-1.00	-10.2						
1-8	0700	94		0				7	70	7.4	6.1	315	302	0.00	-1.9						
	0800	94		0				10	68	6.7	5.1	313	305	0.00	-2.2						
	0900	89		0				10	65	4.4	3.6	313	309	0.00	-2.2						
	1000	105		0				21	68	5.4	4.2	289	291	0.00	-2.0						
	1100	131		0				18	86	8.7	7.9	292	288	0.00	-1.8						
	1200	131		0	30	25		27	81	8.1	7.8	305	297	0.00	-1.7						
	1300	115		9	4	37		29	78	6.3	5.8	312	308	0.00	-1.1						
	1400	147		12	7	31		18	70	6.9	5.5	308	303	0.00	-1.0						
	1500	141	52	16	8	30		24	76	6.2	5.5	286	286	0.00	-1.2						
	1600	89	58	12	4	34		25	68	4.0	3.6	283	279	0.00	-1.2						
1-18	0300	89	24	0		20		29	55	13.9	14.9	270	266	.05	-4.3						
	0400	89	21	3		39		25	57	14.7	17.3	274	270	.25	-0.9						
	0500	89	21	7		52		26	57	14.8	16.9	272	269	.10	-0.8						

Table 9 (cont)

TABULATION OF DATA COLLECTED (FOR AMES, IOWA)

DATE	TIME	HOURLY SO$_2$ READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO$_2$ EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°F)		VOL. OF FLUE GAS (m^3/sec)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
1975																					
1-18	0600	89	21	5		39		31	57	12.9	14.0	270	268	.20	-1.2						
	0700	89	26	5		33		38	62	11.4	12.3	265	259	.30	-1.7						
	0800	89	24	5		27		39	52	10.1	12.9	260	253	.27	-2.3						
	0900	89	29	4		27		42		11.0	12.4	266	259	-0.29	-1.3						
	1000	89	31	5		48		41		12.0	13.5	272	268	-0.13	-0.5						
	1100	89	37	17		50		35		11.6	12.5	272	268	-0.30	0.9						
	1200	89	26	5	21	46		39		13.1	14.4	285	282	-0.46	1.7						
	1300	94	24	10	30	27		39		13.6	14.2	284	280	-0.35	2.2						
	1400	89	26	7		24		44	57	12.0	12.4	290	285	-0.55	2.4						
	1500	89	29	10		39		42		9.3	10.5	277	276	-0.56	1.0						
	1600	89	37	4		34		35		6.1	7.1	262	258	-0.74	1.3						
	1700	89	37	10		29		39		6.3	7.3	266	260	0.48	0.2						
	1800	89	29	7		35		29		4.0	4.3	301	290	.61	-1.5						
	1900	89	26	1		17		22		3.5	3.0	309	293		-0.5						
	2000	89	24	5		18		27	70	4.7	3.2	272	263	0.00	-0.5						
1-18	2100	89	21	0		20		26	272					0.00	-1.0						
	2200	89	21	3		16		22	481	6.5	6.6	295	290	0.00	-2.6						
	2300	89	21	0		18		25	583	5.9	6.1	293	292	1.25	-2.7						
	2400	89	18	7		14		22	549	6.2	5.9	292	285	1.50	-3.0						
1-19	0100	89	21	1		17		1	471	6.7	6.6	302	280	.86	-3.0						
	0200	89	18	0		14		13	191	5.3	5.2	307	305	1.25	-3.3						
	0300	89	18	5		17		17		5.1	5.2	306	306	1.51	-2.0						
	0400	89	21	0		29		13		4.2	4.7	318	324	0.00	-2.3						
	0500	89	26	1		34		21		8.7		320		0.00	-3.9						
	0600	89	60	5		76		13		12.3		324		0.00	-5.7						
	0700	89	34	0		27		16		12.6		321		0.00	-8.5						
	0800	89	52	3		33		20		13.6		321		.27	-9.9						
	0900	89	47	7		21		29		13.9		321		-0.16	-11.9						
	1000	89	18	14		30		39		15.9		318		-0.06	-11.1						
	1100	89	13	30		38		34		15.2		318		-0.13	-12.1						
	1200	89	16	43		24		34		15.4		317		-0.09	-12.1						
	1300	89	18	69		27		35		14.4		319		-0.12	-12.3						
	1400	89	26	27		25		30		11.9		321		-0.26	-12.0						
	1500	89	47	18		22		41		10.2		323		-0.41	-12.0						
	1600	89	37	17		20		34		11.5		318		-0.43	-12.4						

Table 9 (cont)

TABULATION OF DATA COLLECTED (FOR AMES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED AGGS (mph)		HOURLY WIND DIR. AGGS (°from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°K)		VOL. OF FLUE GAS (m^3/sec)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
1975																					
1-19	1700	89	18	30		18		31		13.2		310		0.37	-13.7						
	1800	89	18	60		18		12		9.7		310		0.41	-15.8						
	1900	89	10	4		16		10		7.8		305		1.93	-19.2						
	2000	89	8	8		14		12		7.2		300		2.53	-20.3						
1-19	2300	89		0		14		16		1.5	1.5	217	219	2.54	-20.7						
1-21	0300	89		0	8			20	86	7.3	8.5	256	245	0.44	-0.3						
	0400	89		0	23			18	86	8.1	9.3	275	272	0.00	0.1						
	0500	89		0	33			25	83	8.2	8.2	271	270	0.48	0.5						
	0600	89		0	35			20	86	8.3	9.2	270	268	0.46	-0.3						
1-21	1100	120		0	44			33	96	12.4	12.6	281	278	-0.63	0.3						
	1200	89		0	10			24	115	16.8	17.0	290	285	-0.57	1.2						
	1300	89		0	4			30	94	17.8	18.9	309	302	-0.58	-1.5						
	1400	89	3	12	4			31	86	16.4	17.1	311	308	-0.15	-6.5						
	1500	89	0	4	3			29		15.8	15.4	305	305	0.14	-8.8						
	1600	89	3	0	0			41	70	13.7	14.0	304	296	0.00	-10.0						
	1700	89	5	0	0			42	70	13.7	12.6	307	302	0.33	-10.6						
	1800	89	5	0	0			31	73	14.9	13.7	310	307	0.31	-12.6						
	1900	89	3	16	0			26	73	16.2	15.9	313	311	0.69	-16.0						
	2000	89	3	18	0			24	70	13.8	15.3	314	308	0.30	-17.5						
	2100	89	5	25	0			34	73	13.7	15.1	315	315	0.47	-18.8						
	2200	89	3	24	0			27	70	12.5	12.2	317	312	0.78	-19.9						
	2300	89	0	35	0			33	68	10.7	8.8	315	312	1.05	-20.7						
	2400	89	3	0	0			34	70	7.9	8.3	310	308	1.44	-21.4						
1-22	0100	89	3	0		0		25		9.1		309		1.62	-22.4						
	0200	89	0	0		0		33	57	5.5	4.6	300	286	1.83	-22.9						
	0300	89	0	0		0		29	71	5.3	3.9	296	292	2.53	-23.2						
	0400	89	3	0		0			68	6.1	4.8	299	296	2.54	-22.1						
	0500	89		0		0		0	68	5.8	5.2	299	293	2.53	-23.8						
1-22	0700	89		0		0		20	68	3.7	4.0	307	297	2.54	-24.0						
	0800	89		0		0		41	70	4.0	2.6	303	292	2.53	-22.8						
	0900	89		0		0		37	68	5.0	5.1	308	294	-0.73	-23.0						
1-25	0400	89							60	14.1	15.1	261	259	0.28	.1						
	0500	89							65	17.7	18.6	267	273	0.04	-1.8						
	0600	89							62	18.4	21.4	276	274	0.00	-4.0						

Table 9 (cont)

TABULATION OF DATA COLLECTED (FOR AMES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°F)		VOL. OF FLUE GAS (m3/sec)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
1975																					
1-25	0700	0							62	17.8	21.0	279	276	0.00	-4.8						
	0800								62	16.3	19.4	279	279	0.00	-6.1						
	0900	0							65	18.3	20.1	277	272	0.00	-6.1						
	1000	0							65	18.1	20.2	281	274	0.00	-6.3						
	1100	0							65	18.4	21.1	280	276	0.00	-6.2						
	1200	0							62	19.3	21.6	282	278	0.00	-6.3						
	1300	0							62	21.7	24.6	280	278	0.00	-5.6						
	1400	0							68	21.1	23.2	276	276	0.00	-5.1						
	1500	0							62	20.2	21.6	280	278	0.00	-5.1						
1-25	1700	55							68	19.9	22.2	281	282	0.00	-5.2						
	1800	42							73	19.6	22.5	280	281	0.00	-6.0						
	1900	47							73	19.7	22.5	282	283	0.00	-6.2						
	2000	60							76	18.5	20.9	287	283	0.00	-6.2						
	2100	76							86	19.5	21.1	287	285	0.00	-6.0						
	2200	58							78	18.8	20.5	284	285	0.00	-5.4						
	2300	50							86	17.6	19.0	287	285	0.06	-5.2						
1-26	0100								70	15.1	16.8	283	282	0.38	-6.5						
	0200	19							70	15.6	17.8	284	284	0.27	-7.2						
	0300	13							76	15.7	18.1	288	286	0.30	-7.3						
	0400								68	13.0	14.8	281	279	0.44	-7.5						
	0500								68	11.9	13.8	278	276	0.30	-8.0						
	0600								68	13.3	14.2	283	280	0.30	-8.5						
	0700								94	10.4	12.5	283	286	0.48	-9.0						
1-26	0900								76	7.6	9.6	297	292	-0.56	-8.0						
	1000								81	9.0	9.9	305	301	-0.58	-7.0						
	1100								70	9.4	10.9	313	311	-0.85	-5.5						
	1200								73	6.4	7.4	305	299	-0.97	-4.6						
	1300								86	6.6	5.7	301	292	-1.02	-3.8						
1-26	1500								76	3.1	2.9	279	275	-1.95	-3.7						
	1600								65	2.1	1.8	296	266	-2.07	-3.3						
	1700								65	0.8	0.2	328	237	1.00	-3.4						
	1800								62	0.7	0.2	338	266		-3.4						

Table 9 (cont)

TABULATION OF DATA COLLECTED (FOR AMES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°F)		VOL. OF FLUE GAS (m3/sec)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
1975																					
1-27	1100								58	5.8	11.1	354	363	-0.88	-6.4						
	1200								60	6.0	12.5	357	361	-0.69	-6.4						
	1300								65	4.8	10.5	365	372	-0.84	-4.5						
	1400								219	7.5	11.6	335	346	-0.54	-3.7						
	1500								431	7.0	12.1	335	344	-0.37	-4.7						
	1600								397	6.4	10.5	335	344	0.00	-5.1						
	1700								329	6.8	9.8	333	343	0.33	-5.2						
	1800								107	6.4	10.6	329	199	0.39	-7.3						
	1900								387	4.8	8.1	334	341	0.63	-8.3						
	2000								96	5.6	7.0	328	328	1.29	-8.5						
	2100								140	5.8	8.8	328	328	1.44	-8.8						
	2200								146	6.0	9.5	327	330	1.42	-9.0						
	2300								329	3.9	7.5	335	303	1.12	-9.5						
	2400								314	3.3	7.4	337	346	1.76	-9.7						
1-28	0100								183	3.0	7.2	344	351	0.06	-9.9						
	0200								162	4.0	6.8	336	346	0.05	-10.0						
	0300								251	4.1	8.0	337	346	0.03	-10.5						
1-29	0200								55	10.2	12.5	264	256	0.00	-2.5						
	0300								55	11.4	12.1	263	261	0.00	-4.0						
	0400								52	11.4	16.4	260	254	0.00	-4.8						
	0500								47	10.1	13.8	260	255	0.00	-6.0						
	0600								49	14.9	18.6	265	259	0.00	-6.5						
	0700								52	14.5	18.3	261	257	0.00	-8.0						
	0800								49	14.9	18.7	264	258	0.00	-9.5						
	0900								55	17.5	18.1	270	262	0.00	-9.7						
	1000								47	17.6	18.4	274	267	-0.02	-8.8						
	1100								55	17.0	17.6	276	270	0.00	-6.4						
	1200								68	16.0	18.2	281	279	-0.11	-5.6						
	1300								68	13.4	14.0	278	274	-0.31	-5.1						
	1400								86	15.5	16.6	286	281	-0.45	-4.0						
	1500								55	13.7	15.0	285	280	-0.45	-3.8						
	1600								36	11.1	13.2	279	299	-0.35	-4.3						
	1700								41	8.6	9.9	277	271	0.33	-4.6						
	1800								83	6.5	7.1	299	294	0.67	-6.2						
	1900								76	4.8	4.3	272	271	2.54	-8.5						

Table 9 (cont)

TABULATION OF DATA COLLECTED (FOR AMES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES		VOL. OF FLUE GAS (m^3/sec)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
1975																					
1-30	2300								65	2.1	4.8	328	351	2.49	-8.3						
	2400								62	3.2	6.0	342	299	2.11	-9.0						
1-31	0100								191	3.4	7.5	331	341	1.83	-10.2						
	0200								141	2.8	5.2	321	335	1.90	-10.5						
	0300								76	5.3	8.0	323	356	1.79	-11.1						
	0400								246	5.1	8.9	330	339	1.20	-11.8						
	0500								130	5.9	9.4	339	347	1.12	-12.0						
	0600								117	4.4	8.9	345	351	0.73	-12.9						
	0700								94	3.5	7.6	342	350	1.22	-13.2						
	0800								107	3.7	8.4	349	358	1.29	-13.3						
2-4	1600 →	Sulfur dioxide, wind speed and wind direction data collection equipment not functioning.																			
2-6	2100																				
2-7	1300 →	Sulfur dioxide, wind speed and wind direction data collection equipment not functioning.																			
2-9	0600																				
2-10	2300 →	Sulfur dioxide, wind speed and wind direction data collection equipment not functioning.																			
2-11	0600																				
2-11	1500 →	Sulfur dioxide, wind speed and wind direction data collection equipment not functioning.																			
2-12	1000																				

Table 10

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES ([illegible])		[illegible] GAS (m³/sec.)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
2/12/75																					
	1100													-.966	-7.3						
	1200	0								7.0	4.4	238	288	-.937	-7.2						
	1300	12								7.0	4.4	253	313	-.878	-6.6						
	1400	58								7.7	6.0	256	292	-.547	-7.3						
	1500	5								9.9	7.8	253	293	-.732	-8.8						
	1600	19								10.6	8.0	261	300	-.508	-9.8						
	1700	0								13.2	7.5	288	312	-.703	-10.6						
	1800	0								12.1		285		.389	-11.8						
	1900	0								10.6	6.3	289	324	.925	-13.7						
	2000	2								9.7	5.3	286	323	1.25	-14.5						
	2100	0								9.3	4.3	295	335	1.44	-14.7						
	2200	0								6.2	4.3	286	327	1.50	-14.8						
	2300	0								5.7	3.5	282	323	2.00	-15.0						
	2400													2.21	-15.4						
2/13/75																					
	0100	0								4.8	2.7	298	346	1.83	-16.0						
	0200	0								4.8	2.2	311	340	1.29	-16.5						
2/15/75																					
	0500	0		43	85	103	31	109		6.5	2.5	306	360	0.00	-7.64						
	0600	0		62	30	97	18	71		7.7	3.2	311	342	0.00	-7.54						
	0700	11		68	72	120	29	107		9.5	4.1	301	335	0.00	-7.24						
	0800	13		71	54	115	24	95		9.9	4.4	301	336	0.00	-7.04						
	0900	13		59	46	127	24	93		11.2	4.7	303	335	0.00	-6.94						
	1000	13		60	39	123	18	85		11.5	5.5	300	336	0.00	-7.24						
	1100	24		94	41	110	24	99		13.3	5.5	305	339								
	1200			106	49	122					5.0		341	0.00	-3.6						
	1300	11		116	81	128	39	123		13.3	4.6	304	344	0.00	-3.0						
	1400	13		118	81	127	42	127		14.1	5.5	308	340	0.00	-2.8						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (°from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°C)		VOL. OF GAS (m^3/sec.)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
2/18/75	1100	0	0	21			0	30		10.3	7.5	237	283	0.00	-4.6	755	576	436	405	139	156
	1200	0	16	33				43		9.7	6.2	229	274	0.00	-4.1	755	576	436	405	139	151
	1300	0	16	30			0		9	11.8	8.4	238	280	0.00	-3.9	755	576	436	405	146	154
	1400			35	5		0	44	9	12.1	9.6	213	280	0.00	-3.7	755	576	436	405	146	154
	1500	24	5	38	7		5	48	7	15.3	10.2	239	280	0.00	-4.0	755	576	436	405	146	154
	1600	29	10	43	7		8	48	7	14.1	9.2	238	279	0.00	-3.8	755	576	436	405	141	154
	1700	29	18	72	22		8	52	0	12.4	8.2	233	272	0.00	-4.0	755	576	436	405	141	154
	1800	24	13	41	18		5	51	0	14.1	9.2	230	275	0.00	-6.94	755	576	436	405	143	154
	1900	21	13	58	7		5	47	2	14.3	8.9	272	289	0.00	-7.84	755	576	436	405	143	154
	2000	18	8	29	7		5	41	2	15.1	8.8	247	290	0.00	-7.84	755	576	436	405	143	154
	2100	21	8	69	7		5	39	2	11.7	8.4	238	287	0.00	-7.74	755	576	436	405	143	154
	2200	21	8	84	7		5	37	2	12.8	7.2	245	284	0.00	-9.34	755	576	436	405	143	154
	2300	13	10	60	9		5	42	2	10.0	7.4	232	276	0.00	-10.6	755	512	436	405	141	137
	2400	18	8	47	14		3	38	2	7.8	6.6	219	275	0.00	-11.4	755	433	436	405	141	119
2/19/75	0100	13	8	27	5		3	31	0	4.5	5.3	222	284	1.31	-12.3	440	391	422	411	105	84
	0200	13	5	54	5		3	20	0	4.5	4.4	210	283	2.50	-12.0	252	341	422	400	60	77
	0300	13	5	30	0		0	18	0	6.0	3.2	201	273	2.42	-13.0	252	341	422	394	61	77
	0400	13	5	25	0			18	0	6.0	1.2	198	232								
2/21/75	1600	7		9			5	76	31	11.0	5.4	207	245	-.596	5.8		554		427		170
	1700	13		16			8	81	13	10.4	6.2	210	268	-.654	3.3		502		422		152
	1800	9		7			8	69	4	6.8	5.6	206	266	.358	2.1		502		422		152
	1900	4		0			0	52	9	5.8	2.5	173	228	.381	-0.243		502		422		152
	2000	0	18				0	48	4	7.2	1.9	185	219	.480	-0.143		502		422		152
	2100	0	16				0	41	14	5.9	3.1	202	247	.445	-0.343		502		422		152
	2200	0	16				0	39	14	6.9	3.1	205	246	1.12	-0.243		502		422		152
	2300	0	16				0	41	7	7.3	3.9	210	254	1.03	-0.743		502		422		152
	2400	0	16					31	9	6.0	6.8	192	314	1.01	-0.943		413		422		125

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED PDGS (mph)		HOURLY WIND DIR. PDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°K)		VOL. FLUE GAS (m³/sec.)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
2/22/75																					
	0100	0	10					31	11	7.1	8.1	219	277	.304	-1.34						
	0200	0	10					31	9	7.4	5.6	225	274	0.00	-1.54						
	0300	0	10					30	9	6.9	6.5	225	287	.357	-1.84						
	0400	0	10				0	26	14	13.2	6.5	258	296	0.00	-2.04						
	0500	22	8				52	26	11	11.1	7.4	261	302	.451	-2.44						
	0600	11	8				113	27	16	10.9	6.7	263	300	.828	-3.34						
	0700	16	8				34	25	13	8.8	6.1	256	300	1.16	-4.24						
	0800	39	5				99	25	11	8.0	6.7	259	299	1.29	-4.84						
	0900	228	5				317	21	9	10.6	6.7	269	309	-.440	-3.4						
	1000	230	5				301	21	9	9.4	6.9	266	305	-.625	-3.4						
	1100	45	5				13	296	11	11.7	6.7	279	312	-.615	-2.9						
	1200	0	5					284	11	12.2	6.8	279	317	-.625	-2.0						
	1300	0	8					504	11	11.9	6.5	279	324	-1.23	-2.4						
	1400	0	8				0	254	11	11.5	5.9	279	320	-1.48	-2.2						
	1500	0	8				34	588	11	12.6	6.4	284	324	- .781	-2.2						
	1600	0	8					219	11	15.7	9.3	290	321	- .683	-1.0						
	1700	0	8						9	16.3	8.9	285	320	- .498	-1.4						
	1800		5						7	13.5	7.7	275	313	.342	-2.0						
	1900	0	5					622	9	14.4	8.4	278	318	0.00	-3.64						
	2000	0	5					559	7	13.8	8.2	283	319	.328	-3.54						
	2100	0	5					645	7	12.4	8.0	279	317	.369	-4.04						
	2200	0	5					139	7	11.7	7.4	275	314	.366	-3.94						
	2300	0	5				0	47	7	11.7	6.5	270	300	.668	-4.54						
	2400	0	5				0	30	5	11.7	7.8	255	297	.561	-5.34						
2/23/75																					
	0100		5		33		34	144	7	12.9	8.9	279	316	.346	-5.74						
	0200	0	5				5	192	19	12.4	8.0	272	313	.190	-6.74						
	0300	0	5		3			257	16	14.9	9.1	281	317	.422	-7.24						
	0400	0	5					310	18	18.9	11.0	286	321	.221	-6.74						
	0500	0	52					64	16	15.2	6.3	292	319	.0640	-7.04						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°C)		[illegible] GAS (m³/sec.)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
2/23/75 (cont.)																					
	0600	0	29					109	16	14.6	6.5	291	327	.0815	-7.44						
	0700	0	18					42	18	12.4	5.9	294	328	.00	-7.24						
	0800	0	39					38	16	10.9	5.2	292	336	.00	-7.04						
	0900	0	55					123	13	10.3	5.4	285	328	.00	-7.04						
	1000	0	10					200	13	12.2	7.2	276	313	.00	-7.04						
	1100	0	8					267	13	12.7	8.9	277	315	-.683	-4.7						
	1200	0	8					279	13	15.0	9.1	279	314	-.428	-3.7						
	1300	0	13					105	13	16.9	9.6	286	326	-.557	-3.0						
	1400	0	16		0			48	13	16.4	8.8	289	330	-.405	-2.7						
	1500	0	34					44	14	16.7	7.8	293	334	-.229	-3.4						
	1600	0	55					120	14	16.1	8.9	286	321	0.00	-4.7						
	1700	0							13	17.9	9.7	287	318	0.00	-4.8						
	1800		84					48	11	16.8	9.2	286	327	0.00	-6.54						
	1900	0	44					29	16	18.9	11.3	285	323	0.00	-7.14						
	2000	0	55					25	18	21.0	11.1	287	324	0.00	-7.64						
	2100	0	60					22	21	18.1	9.9	284	321	0.00	-7.54						
	2200	0	13		0			839	18	18.6	11.6	280	317	0.00	-7.24						
	2300	0	5					649	14	21.6	12.6	276	316	0.00	-7.54						
	2400	0	5					756	16	23.6	12.9	278	318	0.00	-7.74						
2/24/75																					
	0100	0	8		0			383	16	22.4	13.6	279	322	0.00	-6.84	545	560	450	411	139	119
	0200	0	8					890	16	21.7	13.0	275	318	0.00	-5.54	465	560	450	411	120	111
	0300	0	3					623	16	23.3	13.5	270	315	0.00	-5.04	465	560	450	411	120	111
	0400	0	3					200	16	22.6	13.2	272	310	0.00	-5.54	465	560	450	411	120	111
	0500	0	3					242	13	22.0	13.2	271	309	0.00	-5.04	465	560	450	411	120	111
	0600	0	3		0			230	13	24.2	13.5	264	309	0.00	-5.54	465	560	450	411	120	111
	0700	0	0		29			12	11	24.0	14.2	263	312	0.00	-4.94	567	738	450	411	150	141
	0800	0	0					330	11	26.2	13.8	264	312	0.00	-4.74	567	885	450	422	150	173

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°K)		VOL. [illegible] GAS (m³/sec)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
2/24/75 (cont.)																					
	0900	0	0					79	11	26.4	15.5	264	313	0.00	-5.44	567	843	450	427	150	178
	1000	0	3					305	11	27.1	15.7	265	313	0.00	-4.84	567	632	450	430	150	124
	1100	0	3					157	11	25.0	14.7	263	315	0.00	-3.6	567	815	450	430	150	160
	1200	0	3					68	11	23.4	14.1	262	312	0.00	-2.5	567	815	450	430	143	164
	1300	0	3		97			21	11	22.8	12.6	258	310	0.00	-2.7	567	815	450	430	143	164
	1400	0	5		0			101	11	20.9	11.6	261	313	0.00	-2.4	567	801	450	430	143	161
	1500	0	5		68		18	88	9	19.1	10.3	261	308	0.00	-4.54	567	801	450	430	140	161
	1600	0	5		69		3	64	7	15.9	9.2	262	310	0.00	-1.2	567	825	450	430	140	166
	1700	17	8		211		60	38	9	13.9	8.5	258	306	-.508	-0.4	536	825	450	430	137	166
	1800	56	8		98		115	26	9	12.4	7.7	247	293	.358	-1.3	536	825	450	433	137	172
	1900	0	5		0			24	7	12.4	6.3	244	297	.422	-2.94	536	825	450	433	137	172
	2000	0	5					21	0	10.8	5.4	234	284	.652	-3.94	536	825	450	433	137	172
	2100	0	10		7			14	2	8.7	7.5	215	275	1.93	-4.0	536	825	450	433	137	172
	2200	0	24		12			13	0	8.1	5.8	208	275	1.16	-4.84	536	825	450	433	137	172
	2300	0	3		13			27	0	5.3	4.5	192	264	1.37	-4.3	536	825	450	433	139	185
	2400	0	3					7	0	7.7	5.5	189	253	1.65	-4.3	337	825	450	433	89	185
2/25/75																					
	0100	0	8					13	2	16.5	10.7	223	281	.177	-2.24	241	294	422	422	66	117
	0200	0	3					8	5	24.5	12.5	239	289	.0601	-0.943	241	294	422	422	66	117
	0300	0	3					10	5	25.3	13.5	244	285	.0133	0.057	241	244	422	422	66	97
	0400	0	3					12	5	31.0	15.6	240	284	.00	-0.043	241	244	422	422	66	97
	0500	0	3					7	5	32.2	18.0	241	287	.00	-1.64	241	244	422	422	66	97
	0600	0	3					14	0	30.5	17.1	239	285	.00	-3.24	385	244	425	422	99	97
	0700	0	3					7	0	31.5	16.0	237	284	.100	-4.04	505	408	427	422	121	163
	0800	0	0					4	2	26.6	14.8	230	282	.100	-4.44	576	408	433	422	139	163
	0900	0	0					1	2	28.4	15.0	232	282	.00	-2.2	576	408	433	422	139	163
	1000		10					0	5		15.1		278	.00	-1.0	576	408	433	422	139	163
	1100								16		16.0		280	.00	0.4	576	408	433	422	139	163

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO$_2$ READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO$_2$ EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASSES (°K)		VOL. OF FLUE GAS (m^3/sec.)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
2/25/75 (cont.)																					
	1200								101	25.2	16.8	224	282	.00	1.3	576	408	433	422	139	163
	1300		5				0	20		26.8	15.0	224	275	-.100	2.0	576	430	433	439	139	178
	1400		0	63			0	27		22.7		218		-.100	2.6	576	430	433	439	139	178
	1500			50			3	39		24.3		221		.00	3.1	576	430	433	439	139	178
	1600			63			13	42		21.5		217		.00	3.4	576	404	433	439	139	167
	1700			67			8	39		17.2		202		.00	3.5	576	404	433	439	139	167
	1800			79			8	42		15.9		197		.0617	3.2	576	404	433	439	139	167
	1900		0	64			5	37		15.6		198		.539	-0.243	576	404	433	439	139	167
	2000			50			5	41		12.0		193		.294	-0.743	576	404	433	439	139	167
	2100		0	52			8	41		13.4		205		.312	-1.34	576	404	433	439	139	167
	2200	0	0	62			8	47		13.7		219		.290	-1.74	576	404	433	439	139	172
	2300	0	3	52			5	27		15.2		224		.259	-1.94	574	404	433	439	139	172
	2400	0	0	31			3	27		13.0		219		.304	-2.24	41-	306	433	439	102	133
2/26/75																					
	0100	0		64			5	27		9.4		198		.286	-2.74						
	0200	0		31			5	21		8.5		199		.312	-3.34						
	0300	0		64			10	17		8.1		197		.224	-3.54						
	0400	0		31			5	17		8.8		189		.255	-3.94						
	0500	0		52			3	13		9.7		200		.366	-4.54						
	0600	0		22			10	17		8.3		206		.351	-4.64						
	0700	0		39			5	24		14.5		222		.162	-4.54						
	0800	0		65			3	50		16.9		222		.255	-5.04						
	0900	0		18			8	38		16.7		218		-.0305	-3.30						
	1000	0		103			8	18		15.2		218		-.155	-2.60						
	1100	0		34			5	8		18.5		228		-.136	-1.6						
	1200	0	0	84	17			0		19.3		233		-.163	-0.8						
	1300	0	0	59	33			9		19.3		235		-.185	-0.5						
	1400	0	3	127	37			18		18.2		232		-.197	-0.7						
	1500	0	3	50	37			21		19.2		230		-.722	-2.0						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°K)		VOL. GAS' ([illegible])	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
2/26/75 (cont.)																					
	1600	0	3	51	34			21		17.0		241		-.299	-1.4						
	1700	0	8	71	35			25		17.6		232		-.849	-2.4						
	1800	0	5	76	38			26		14.7		224		.385	-3.54						
	1900	0	3	71	38			31		11.6		220		.00	-3.74						
	2000	0	3	43	30			25		8.2		208		.468	-4.14						
	2100	0	3	42	29			22		5.8		194		1.04	-4.44						
	2200	0	3	44	24			18		5.9		189		1.52	-5.04						
	2300	0	0	37	22			13		6.1		186		1.40	-4.24						
2/27/75																					
	0300	0	0	17	10				0	3.0		193		1.55	-6.3						
	0400	0	0	52	8				0	0.2		171		1.44	-6.9						
	0500	0	0	39	10				0	0.4		139		1.76	-6.6						
	0600	0	0	52	1				0	1.1		101		1.76	-7.3						
	0700	0	0	60	1				0	1.3		117		1.76	-7.8						
	0800	0	0	64	0				0	1.3		60		1.55	-7.7						
	0900	0	0	33	0					1.8		66		-.422	-7.5						
	1000	0		18	16					3.8		95		-.537	-4.0						
	1100	0		92				13		7.1		116		-.182	-1.3						
	1200	0	0	68		7	5	47		9.5		125		-.120	-0.2						
	1300	0	0	96		8	5	50		12.6		125		-.0890	1.4						
	1400	0	5	35	27	25	13	65		12.2		124		.00	1.8						
	1500	5	26	98	4	68	31	111		10.9		128		.00	3.3						
	1600	0	10	90		35	18	81		12.0		145		.00	3.4						
	1700	0	3	43		22	10	63		13.3		154		.00	3.7						
	1800	0	3	69		16	10	65		14.2		167		.219	3.5						
	1900	0	5	69		20	10	65		11.4		167		.668	1.7						
	2000	0	5	90		16	10	64		9.7		177		.925	-0.243						
	2100	0	5	69		21	10	62		10.4		189		.711	-0.643						
	2200	0	5	51		52	10	67		11.1		198		1.03	-1.34						
	2300	0	8	68		62	10	63		10.9		219		1.27	-2.54						
	2400	0	5	69		9	10	54		13.7		231		.358	-2.94						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°K)		VOL. GAS (m³/sec)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
2/28/75																					
	0100	0	3	47		12	8	48		14.0		242		.499	-5.14	319	211	422	411	75	101
	0200	0	3	52		5	8	51		12.0		244		1.65	-5.64	335	229	422	411	75	109
	0300	0	3	89		5	18	79		8.1		259		1.93	-6.14	295	211	422	411	71	101
	0400	0	3	44		10	13	50		7.2		230		1.86	-6.94	295	211	422	411	71	101
	0500	0	3	75		0	8	42		5.7		213		2.25	-7.44	295	211	422	411	71	101
	0600	0	0	58		0	8	39		4.6		213		2.51	-7.94	295	211	422	411	71	101
	0700	0	0	88		0	8	33		5.2		224		2.52	-7.1	441	290	433	405	100	124
	0800	0	0	20			3	7		5.4		198		-.516	-7.6	658	377	433	416	145	165
	0900	0	0	43			3	7		5.8		204		-.555	-7.0	658	365	433	427	145	164
	1000	31	0	29			10	20		4.7		201		-1.25	-5.5	658	365	433	427	145	164
	1100	10	3	69		0	37	24		4.5		230		-.985	-3.9	658	365	433	427	145	164
	1200	0	94	60	58	4	24			5.9		269		-.985	-3.1	658	365	433	427	145	164
	1300	0	136	88		7	65			5.4		279		-.907	-2.7	658	365	433	427	145	164
	1400	0	84	52			39			4.0		297		-1.41	-2.2	658	365	433	427	145	164
	1500	163	86	90						1.9		301		-1.84	-1.7	658	365	433	427	145	164
	1600	29	50	82	89		29	366		1.5		330		-2.03	-1.8	573	320	427	427	127	148
	1700	45	44	81	127		37	183		1.4		295		-2.01	-1.7	484	320	427	427	111	148
	1800	26	55	75	99		55	187		1.4		324		.789	-2.0	385	254	427	427	91	117
	1900	7	39	69	42		39	132		1.5		342		1.59	-4.26	385	254	427	427	91	114
	2000	0	24	68			18	69		2.6		350		1.59	-2.5	457	349	416	433	103	159
	2100	0	3	58			13	52		2.1		341		1.59	-3.0	385	254	427	427	91	114
	2200	0	0	62			10	47		1.0		355		1.52	-5.16	335	349	394	427	74	172
	2300	0	0	33			10	42		0.6		411		1.56	-3.7	0	293	0	427	0	144
	2400	0	0	51			8	29		0.2		161		2.59	-4.9	0	240	0	427	0	118
3/1/75																					
	0100	0	0	85			3	12		0.4		142		2.56	-4.7						
	0200	0	0	62			0	5		1.0		158		2.57	-6.0						
	0300	0	0	38			0	0		0.9		265		2.54	-5.4						
	0400	0		33			0			0.3		215		2.51	-5.7						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED AVGS (mph)		HOURLY WIND DIR. AVGS (°from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°K)		VEL. OF EXHAUST GAS (m/sec.)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
3/1/75 (cont.)																					
	0500	0		5			0			2.2		196		2.54	-6.1						
	0600	0		43			0			1.0		216		2.51	-6.6						
	0700	0		0			0			1.3		210		2.53	-7.3						
	0800	0		33			0			2.0		203		- .913	-8.1						
	0900	0		59			0			1.6		227		- .283	-6.9						
	1000	0	0	39			0		8	5.4		279		-.498	-6.7						
	1100	0	31	35			0		14	11.2		285		-.299	-6.4						
	1200	0	3	80			3		89	13.1		279		-.405	-6.4						
	1300	0	0	77			18		174	14.3		267		-.381	-6.4						
	1400	0	0	35			8		222	15.6		275		-.408	-5.8						
	1500	0	3	77			5		157	15.4		274		-.218	-5.9						
	1600		0	60			13		51	14.4		260		-.323	-6.4						
	1700		3	98			63		39	14.3		251		-.547	-6.2						
	1800		3	67			63		46	15.8		248		.352	-7.24						
	1900		3	51			63		43	14.1		250		.346	-8.24						
	2000		3	42			55		42	10.0		255		.428	-8.94						
	2100		3	35	82		97		43	10.3		262		.393	-9.54						
	2200		3	59			10		63	10.8		268		.457	-9.74						
	2300		3	51			8		166	12.2		273		.393	-9.74						
	2400		3	72			8		67	11.1		267		.275	-9.54						
3/2/75																					
	0100		3	68			21		56	12.6		268		.00	-9.54						
	0200		0	54			8		85	12.8		269		.291	-9.44						
	0300		3	52	7		71		39	11.4		261		.328	-9.54						
	0400		0	71			13	39		13.5		264		.283	-10.5						
	0500		3	81			8	105		17.2		269		.197	-10.4						
	0600		3	57			8	43		11.7		263		.775	-11.0						
	0700		3	79			5	92		10.7		270		.796	-10.1						
	0800		3	69			5	43		9.7		277		-.253	-10.7						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED (mph)		HOURLY WIND DIR. (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES		VEL. OF EXHAUST GAS	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
3/2/75 (cont.)																					
	0900		5	107			8	255		8.9		274		-.222	-10.6						
	1000		3	58			10	202		15.4		274		-.334	-10.3						
	1100		10	46			8	64		14.8		274		-.625	- 9.3						
	1200		18	54			10	130		15.1		282		-.299	- 8.1						
	1300		39	71			8	51		11.2		280		-.264	- 7.0						
	1400		8	55			10	46		9.7		276		-.475	- 6.4						
	1500	2	29	56			10	39		10.4		280		-.596	- 6.6						
	1600	0	10	97			5	133		10.3		273		-.713	- 6.7						
	1700	0	10	90			8	205		10.8		272		-.713	- 8.54						
	1800	0	8	68				94		12.0		277		.397	- 8.54						
	1900	0	10	41				90		11.2		272		.471	- 9.54						
	2000	0	8	103				178		9.6		263		.574	-10.0						
	2100	0	5	65				75		8.0		273		.527	-10.0						
	2200	0	5	56				85		6.5		260		1.18	-11.4						
	2300	9	5	67	31		29	33		4.8		253		.597	-11.6						
	2400	0	5	48	29		3	26		5.1		256		2.21	-12.2						
3/3/75																					
	0100	0	5	48				29		4.8		257		2.07	-12.6	0	279	0	419	0	126
	0200	0	5	44				39		4.1		257		2.42	-13.0	0	275	0	416	0	124
	0300	0	3	92				52		4.2		246		2.51	-13.8	0	275	0	415	0	122
	0400	0	3	59				26		5.8		220		2.32	-14.3	0	259	0	414	0	117
	0500	0	0	39				20		5.6		214		2.18	-14.3	0	259	0	414	0	117
	0600	0	0	73				17		5.3		211		2.49	-13.5	0	291	0	415	0	127
	0700	0	0	51				9		5.7		216		2.04	-14.0	247	324	396	416	43	140
	0800	0	0	31				5		6.2		219		- .832	-14.4	503	366	402	422	85	160
	0900	0	0	73			5	0		6.1		225		- .573	-13.5	592	383	412	426	101	141
	1000	222.9	0	47	266		165	10		5.9		246		-1.84	-12.3	843	397	427	436	143	192
	1100	319.8		34	783		275	143		4.2		259		-1.68	-10.4	843	412	427	436	143	192
	1200	171.4	0	67	933		188	145		3.6		242		-2.08	- 8.3	843	412	427	436	141	192
	1300	0	8	43			3	68		3.8		204		-1.91	- 6.5	843	251	427	439	134	117
	1400	99.5	13	44			26	71		4.7		205		-1.99	- 4.2	843	359	427	436	136	166

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED [illegible]		HOURLY WIND DIR. [illegible] (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES [illegible]		[illegible]	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
3/3/75 (cont.)																					
	1500	17	3	41			26	60		5.4		237		- 1.93	-4.0	843	340	427	433	136	159
	1600	5	5	99			34	60		5.1		229		- 1.14	-3.6	843	302	427	430	136	140
	1700	96.8	5	54	128		99	67		5.6		248		- 1.53	-5.26	718	302	422	430	120	140
	1800	2	5	31			5	64		5.1		226		.821	-5.24	718	302	422	429	120	141
	1900	0	5	42			3	62		3.7		202		.711	-5.4	718	302	422	427	118	141
	2000	0	5	50			0	44		4.0		183		2.51	-7.84	771	383	425	433	127	176
	2100	0	3	50			0	48		4.0		195		2.53	-6.9	841	383	427	436	141	177
	2200		3	26			0	41		5.1		188		2.52	-7.6	841	383	427	436	141	177
	2300		3	31			0	37		5.2		191		2.42	-8.1	669	383	427	436	115	175
	2400		0				0	39		4.0		195		2.54	-8.6	383	240	422	436	67	109
3/4/75																					
	0100		0	20			0	34		2.1		185		2.53	-9.6	590	190	411	416	67	94
3/5/75																					
	1500	0		22			5			4.5		173		0.00	0.6	727	470	427	408	141	113
	1600	0		153			8		0	4.9	3.3	182	254	0.00	1.0	725	508	422	408	140	120
	1700	0		46			8	50	5	4.9	5.0	180	265	0.00	1.4	555	704	422	408	111	168
	1800	0		73			5	50	12	6.8	5.0	205	285	0.00	- .243	555	704	422	408	109	170
	1900	0		60			5	47	22.5	5.9	4.2	220	293	0.00	- .943	555	704	422	408	108	168
	2000	0		51			3	47	16	7.9	4.4	227	302	0.00	0.4	690	704	427	411	133	169
	2100	0		51			24	46	19	7.9	4.4	230	297	0.00	0.4	698	669	427	411	135	162
	2200	0		41			16	44	21	8.9	5.9	225	293	0.00	0.1	698	566	427	411	138	141
	2300	0		43			16	44	21	8.1	5.2	226	296	1.25	-1.84	659	444	427	414	130	111
	2400	2		43			32	43	58	7.7	4.9	233	303	1.39	-0.7	402	427	427	411	88	108

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO$_2$ READINGS ($\mu g/m^3$)								HOURLY WIND SPEED (mph)		HOURLY WIND DIR. (°from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO$_2$ EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES		VOL. OF GAS (m³/sec)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
3-6-75																					
	0100	2		81			5	47	19	1.7	0.2	230	286	2.52	-0.7	572	0	416	0	69	0
	0200	0		43			0	29	9	1.3	0.0	179	277	2.52	-2.1	572	0	411	0	69	0
	0300	0		37				29	11	1.8	0.3	180	272	2.28	-3.1	572	0	411	0	70	0
	0400	0		5				22	11	2.1	1.2	216	298	2.55	-3.9	572	0	411	0	70	0
	2100	0	21	47			10	55	19	11.1	5.6	294	362	0.00	-5.94						
	2200	0	26	33	8		10	65	11	10.2	4.8	291	351	0.00	-5.64						
	2300	0	18	99			5	50	11	7.9	4.1	288	325	0.00	-5.24						
	2400	0	21	56	0		8	55	17	9.7	5.3	278	341	0.00	-5.14	841	0	422	0	104	0
3-7-75																					
	0100	0	21	40			8	52	11	13.1	6.7	275	339	0.00	-4.94	607	0	422	0	104	0
	0200	0	44	71	3		10	65	16	12.2	7.6	268	330	0.00	-4.84	607	0	422	0	105	0
	0300	0	84	59	0		10	60	17	10.8	8.2	256	323	0.00	-4.94	607	0	422	0	105	0
	0400	0	39	60	8		18	77	31	12.5	8.7	252	319	0.00	-3.6	607	0	422	0	105	0
	0500	0	31	42	9		16		17	11.1	9.9	251	318	0.00	-4.1	607	0	422	0	104	0
	0600	0	21	38	10		13	374	14	11.2	10.2	243	312	0.00	-5.1	607	0	425	0	106	0
	0700	0	18	36	18		5	84	11	11.8	9.4	244	312	0.00	-6.5	607	0	422	0	107	0
	0800	0	18	35			5	166	9	11.7	10.8	240	314	- .268	-8.0	665	0	422	0	114	0
	0900	0	18	44	65		10	52	5	12.6	7.5	243	303	- .283	-7.5	841	0	425	0	143	0
	1000	165	21	46	297		351	46	9	10.3	7.5	239	299	- .416	-6.5	841	0	427	0	143	0
	1100	183	21	33	217		275	44	2	9.3	7.1	233	294	- .112	-5.2	715	0	430	0	119	0
	1200	78.5	18	44	73		199	43		9.9		233		- .171	-4.3	714	0	427	0	116	0
	1300	35	18	41	24		84	46		11.5		232		- .253	-3.2	714	0	427	0	115	0
	1400	0	18	55	0		21	46		12.3		222		- .381	-2.1	714	0	427	0	114	0
	1500	0	18	62			13	43		15.3		226		- .155	-2.4	714	0	430	0	116	0
	1600	0	8	55			37	37		17.7		225		.00	-1.5	714	0	427	0	117	0
	1700	0	3	71			34	20		14.8		226		.00	-2.5	714	0	425	0	117	0
	1800	2	3	51			55	22		14.2		227		.00	3.9	714	0	425	0	117	0
	1900	35	3	52			120	25		14.2		228		.00	-6.04	714	0	422	0	116	0
	2000	0	3	39			29	37		13.7		222		.268	-6.64	714	0	422	0	114	0
	2100	0	3	65			8	33		14.3		223		.539	-7.54	714	0	422	0	114	0
	2200	0	3	73			8	37		14.3		221		.687	-8.64	714	0	422	0	114	0
	2300	0	3	52			5	31		15.9		226		.457	-9.54	841	0	422	0	138	0
	2400	0	3	44			10	33		13.7		228		1.37	-10.2	811	0	422	0	140	0

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (°from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°C)		VEL. [illegible] GAS (m/sec.)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
3-08-75																					
	0100	84	0	25			202	33		10.7		231		.989	-10.6						
	0200	34.5	3	65			73	38		10.3		230		.882	-11.3						
	0300	52	3	33			76	34		10.5		229		.818	-11.6						
	0400	24	0	54			34	33		10.9		228		.882	-12.3						
	0500	0	8	50			10	137		11.1		244		1.42	-13.1						
	0600	0	10	41			3	119		11.6		242		1.50	-14.0						
	0700	0	5	31			3	52		9.8		242		1.70	-14.8						
	0800	0	3	18			0	132		8.2		240		- .668	-13.9						
	0900	0	5	38			3			8.9		248		- .313	-13.2						
	1000	0	94	48			10	68		7.3		253		- .917	-11.6						
	1100	0	55	60			13	231		5.6		250		- .907	-10.2						
	1200	0	63	101			13	196		5.1		254		-1.97	- 8.6						
	1300	0	139	102				165	9	4.3	2.7	253	335	-2.07	- 7.7						
	1400	0	52	75				64	14	3.5	2.6	284	336	-2.45	- 7.3						
	1500	0	18	38				39	11	4.3	2.2	294	345	-2.31	- 6.8						
	1600	0	39	33				39	9	4.2	3.0	290	344	-1.72	- 5.1						
	1700	0		35			3	46	14	4.1	2.8	295	351	-2.35	- 6.7						
	1800	0		63			3	55	14	2.3	1.0	293	344	1.14	- 6.9						
3-12-75																					
	0100	0	13	12		0	16	96	25	1.3	0.0	208	310								
	0200	0	13	24		0	16	92	16	3.0	2.2	209	301								
	0300	0	18	33		0	18	84	19	4.1	2.5	207	291								
	0400	78	13	9		0	13	86	26	6.1	4.4	204	277								
	0500	0	16	13		0	16	90	23	10.1	6.3	206	279								
	0600	0	13	5		0	13	98	23	11.4	7.3	217	287								
	0700	0	10	37		0	13	95	21	13.9	7.4	220	299								
	0800	0	13	37		0	16	98	26	15.0	7.2	226	294								
	0900	87	18	59		0	188	103	23	12.5	7.8	234	302								
	1000	184	8	59		0	359	79	5	13.7	11.4	238	311								
	1100	13	0				21		11	18.9	9.4	250	314								
	1200	25	0			44	39		17	19.1	9.2	244									
	1300	0	0			42	0			22.0		252									
	1400	23	0			39	50	246		18.2	8.1	249	308								
	1500	108	0			69	246	43		15.3	11.5	234	305								
	1600	77	0		105	52	162	50		14.2	10.4	234	293								

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDOS (mph)		HOURLY WIND DIR. RDOS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°F)		VOL. GAS (ft³/sec.)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
3-12-75 (cont.)	1700	20	0		118	69	55	50		13.9	11.4	231	294								
	1800	0	3		131	68	5	44		15.1	11.0	224	294								
	1900	0	0		340	60	18	47		13.4	10.3	226	296								
	2000	231	0		301	54	398	47		14.0	9.0	239	307								
	2100	116.5	0		432	55	448	43		10.5	8.0	240	306								
	2200	0	0		131	58	139	43		10.4	7.0	240	305								
	2300	0	0		118	55	0	41		9.2	6.1	244	308								
	2400	0	0		118	47		80		8.3	4.0	245	307								
3-13-75	0100	0	0		118	34		149		5.9	4.2	242	309	2.46	-15.5						
	0200	0	10		118	41		135		3.1	3.3	250	321	2.52	-15.3						
	0300	0	55		118	39		29		3.2	2.8	263	321	2.53	-16.0						
	0400	0	5		118	54	0	33		3.0	2.3	233	319	2.55	-17.1						
	0500	0	10		131		5	65		2.8	2.5	227	305	2.51	-18.3						
	0600	0	3		118	27	5	62		1.3	2.4	237	308	2.52	-19.1						
	0700	0	0		118	47	0	59		3.3	3.4	229	315	2.18	-19.1						
	0800	0	0		118	30	0	92		4.4	3.4	236	315	-1.02	-19.3						
	0900	0	0		105	26	0	71		4.9	4.3	247	322	-1.02	-18.0						
	1000	0				42	0	25		4.7	3.1	275	344	- .966	-15.5						
	1100	0			52		5	35		4.3	3.3	284	365	-1.95	-13.5						
	2300	7			39	35	29	79	7	2.1	1.3	271	340	2.53	-12.3						
	2400	0			39	30	18	59	5	2.2	2.9	252	333	2.55	-13.6						
3-14-75	0100	0			26	26	16	46	2	3.5	3.7	268	333	2.52	-14.6						
	0200	0			39	41	16	46	5	2.2	3.5	228	323	2.21	-15.0						
	0300	0			79	62	16	52	11	2.0	3.4	223	325	2.51	-15.1						
	0400	5			39	97	31	88	14	2.3	1.5	221	314	2.51	-17.8						
	0500	0			39	42	18	54	9	2.7	2.1	203	305	2.39	-16.5						
3-18-75	1100					72	5	0	9			314	177	0.00	2.1						
	1200			39	13	44	8	0	7		1.7	238	303	0.00	3.8						
	1300	51	13	26	13	50	29	35	12	21.6	6.1	243	298	0.00	3.5						
	1400	99	8	13	26	33	107	60	4	6.6	4.5	277	294	0.00	4.5						
	1500	4	5	13	26	33	44	49	4	4.5	5.3	243	296	0.00	4.1						
	1600	0	3	13	39	17	50	50	2	3.5	5.4	246	294	0.00	4.6						
	1700	0	0	13	39	10	24	39	2	2.4	3.8	217	300	-1.33	4.8						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED [illegible] (mph)		HOURLY WIND DIR. [illegible] (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°K)		[illegible] GAS (m³/sec.)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
3-18-75 (cont.)	1800	0	0	13	39	0	21	44	0	4.3	3.3	236	293	.938	6.1						
	1900	0	0		52	5	21	54	0	4.3	4.3	275	320	1.16	5.0						
	2000	0	3		52	12	21	52	0	5.6		271	316	1.59	3.5						
	2100		0		52	13	21	38	4			225	285	1.54	2.4						
	2200				52		16	13	2	4.3	2.1	188	290	0.00	2.3						
	2300				52		13	12	0	3.0	4.0	217	298	0.00	2.3						
3-19-75	2100	4		52	39	69	21	54	19	3.9	2.9	169	245	.818	9.4						
	2200	0		52	39	56	16	41	11	6.8	3.3	170	231	.775	7.9						
	2300	2		52	39	59	18	38	14	6.9	5.9	186	266	1.07	7.5						
	2400	0	5	39	39	54	18	48	8	4.5	3.8	189	291	1.22	6.4						
3-20-75	0100	0	5	39	39	44	13	44	11	2.9	5.1	208	304	2.04	5.4						
	0200	0	3	39	39	46	13	47	9	7.1	5.1	216	296	2.28	5.0						
	0300	0	3	26	39	42	10	47	12	4.4	4.9	232	309	1.97	3.4						
	0400	0	3	26	39	41	8	43	11	5.5	2.9	202	302	2.50	3.3						
	0500	0	3	26	39	0	5	43	9	4.9	2.6	222	299	2.32	1.8						
	0600	0	0	26	39	29	5	33	9	4.8	2.9	234	317	1.65	1.4						
	0700	0	0	13	39	29	0	16	9	3.2	1.1	209	290	.903	- 0.94						
3-21-75	0700	0		13	26	17	3	21	11			234	324	2.51	1.7						
	0800	0		13	26	7	3	5	18			208	309	- .691	1.3						
	0900	0			26	0	0	4	14	2.5		185	298	-1.64	1.1						
	1000	0			13		0	0	7	5.1	4.6	224	300	- .781	1.6						
	1100	0			0	0	0	14	7	10.1	5.7	251	329	- .878	2.7						
	1200	0		0		0	0	22	4	8.2	4.1	265	331	- .428	4.4						
	1300	0		13			0	33	9	7.6	5.4	267	326	.00	6.8						
	1400	0	0	26			8	48	11	6.5	4.5	282	353	.00	7.0						
	1500	0	3	26		18	8	64	16	8.0	4.3	303	348	.00	5.66						
	1600	2	3	26		12	8	68	14	7.9	5.3	272	338	.00	4.46						
	1700	0	5	13		44	8	80	11	6.1	2.8	287	340	.00	3.54						
	1800	0	0	13	13	39	5	65	7	9.5	7.2	289	353	.00	4.16						
	1900	0	0	13	13	34	5	52	11	15.5	8.1	253	321	.00	1.84						
	2000	65	0	13	13	33	5	48	11	16.2	11.7	253	320	.00	1.54						
	2100	0	0	39	13	31	3	47	11	20.5	9.2	259	325	.00	1.54						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED PDGS (mph)		HOURLY WIND DIR. PDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°K)		[illegible]	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
3-21-75 (cont.)	2200	0	0	52	0	26	5	52	9	19.4	11.1	256	321	.00	1.56						
	2300	2	10	13	0	25	13	65	18	15.8	9.7	247	314	.363	1.06						
	2400	0	5	13	0	35	11	63	11	15.1	8.7	255	318	.463	0.557						
3-22-75	0100	2	3	0		37	8	59	11	13.5	8.3	240	306	1.03	5.50						
	0200	2	3	0		37	5	69	9	14.4	9.9	239	309	1.16	4.50						
	0300	0	3	0		39	5	60	12	11.8	6.6	244	302	1.37	3.90						
	0400	2	3	0		35	5	63	11	8.4	5.0	237	301	.603	3.10						
	0500	0	3	0		41	5	52	11	9.5	4.0	234	297	1.57	2.90						
	0600	0	3	0		33	3	50	11	9.3	4.6	231	301	2.21	2.10						
	0700	0	3			37	3	46	7	8.2	3.6	237	298	2.39	1.70						
	0800	0	3			30	0	49	7	4.8	2.4	223	294	- .804	1.30						
	0900	0	0			27	3	39	4	4.9	4.1	206	295	-1.60	1.10						
	1000	0	0			29	3	43	4	8.1	5.1	231	306	-1.49	1.60						
	1100	0	0	0		33	3	50	7	7.1	4.3	263	332	-1.97	2.70						
	1200	0	3	0		38	3	54	9	6.3	2.7	281	353	-1.72	4.40						
	1300	0	5	13		39	5	71	11	4.1	2.2	282	302	-2.05	6.80						
	1400	0	5	0		50	8	76	11	3.1	2.4	273	333	-2.10	7.00						
3-24-75	0800	0	0			20	3	157		18.1	10.4	148	201								
	0900	0	0			18	0	221		18.2	10.3	147	206	0.00	- 4.94						
	1000	0	0			17	0	168		20.1	10.5	157	224	0.00	- 2.20						
	1100	0	0			20	0	127		22.0	12.1	167	237	0.00	- 2.60						
	1200		0			26	0	84		21.7	10.3	173	240	0.00	- 1.40						
	1300		0			38	3	55		20.2	10.7	179	255	0.00	- .600						
	1400					46	0			22.3	10.7	188	227	0.00	- 3.04						
	1500		0			43	3			21.1	12.3	192	261	0.00	- 2.54						
	1600		0			69	8			21.1	14.8	196	266	0.00	- 3.34						
	1700		3			94	10			21.3	12.9	194	263	0.00	- 3.94						
	1800		3			92	10			20.0	13.5	195	265	0.00	- 4.84						
	1900		3			514	10			21.9	14.6	204	273	0.00	- 5.14						
	2000		3			211	8			23.6	15.4	207	273	0.00	- 5.84						
	2100		3			64	8			23.7	14.4	209	276	0.00	- 6.04						
	2200		0			110	8			22.2	13.7	208	274	0.00	- 6.84						
	2300		3			81	8			21.3	13.5	208	275	0.00	- 7.24						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°C)		VOL. GAS (m^3/sec.)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
3-25-75	1600	32	0	13		51	120	251	9	13.3	8.1	250	313	0.00	- 6.10						
	1700	0	0	26		51	13		7	13.2	7.7	253	319	0.00	- 5.60						
	1800	0	10	26		46	8	217	4	11.3	6.2	256	318	0.00	- 6.10						
	1900	0	0	26		52	10	212	12	9.4	5.3	255	319	0.00	- 6.40						
	2000	0	24	39		51	8	143	0	8.6	4.5	263	319	1.00	- 8.36						
	2100	0	5	26		48	8	58	7	7.7	3.3	269	341	.527	- 7.94						
3-28-75	1300			42	85		47		11	7.9	5.3	175	231	- .241	.100						
	1400			47	90		47		10	10.6	5.7	182	241	- .311	1.30						
	1500			54	90		49		11	11.8	7.1	192	246	- .179	1.70						
	1600			63	90		47		14	14.3	9.3	200	265	- .0578	1.30						
	1700	0		34	90		49		11	16.2	10.7	205	266	- .381	.800						
	1800	0		27	93		47		9	17.1	11.7	211	275	- .218	- 1.00						
	1900	0		46	94		47		4	17.0	10.1	215	281	.0578	- 3.64						
	2000	0		43	88		47		2	14.2	7.7	215	281	.212	- 4.14						
	2100	0		43	85		47		2	16.2	10.5	221	283	.255	- 4.74						
	2200			35	89		47		2	18.0	11.1	218	285	.189	- 5.04						
	2300			42	85		44		7	19.4	11.9	218	282	.100	- 5.94						
	2400			35	85		44		0	20.0	11.5	216	283	.100	- 6.34						
3-29-75	0100			47	90		44		5	17.9	12.5	216	276	.208	- 6.94						
	0200			26	93		47		0	17.5	11.1	212	278	.177	- 7.24						
	0300			24	90		44		0	18.3	11.0	211	276	.181	- 7.44						
	0400			59	91		44		0	18.8	9.9	217	283	.397	- 7.94						
	0500			42	103		44		0	16.9	9.7	211	279	.271	- 8.34						
	0600			55	92		44		2	15.9	9.2	210	276	.0698	- 8.64						
	0700	0		48	93		47		2	18.0	8.1	211	268	.0367	- 8.44						
	0800	0		58	98		47		2	18.1	10.8	211	277	- .136	- 6.30						
	0900	0		58	92		44		2	17.8	12.2	210	275	- .0305	- 5.40						
	1000	0		68	92		47		2	19.8	12.9	211	278	- .163	- 4.40						
	1100	0		39	92		47		2	18.6	13.1	209	279	.00	- 3.80						
	1200	0		29	96		47		2	19.2	13.5	214	277	- .0344	- 4.00						
	1300			69	94		47		0	19.9	13.3	219	288	.00	- 5.64						
	1400			39	90		8		0	20.4	13.1	220	281	.00	- 5.24						
	1500			60	86		3		0	20.6	12.8	218	280	.00	- 3.80						
	1600			68	94		3		0	20.9	12.6	219	298	.00	- 2.70						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (cm/sec.)		TEMP. OF EXHAUST GASES (°K)		[illegible] GAS (m³/sec.)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
3-29-75 (cont.)	1700			44	92		3		0	18.5	11.1	220	280	- .264	- 5.14						
	1800			39	92		0		0	18.4	11.4	230	288	- .334	- 5.94						
	1900			89	86		0		0	19.0	11.7	227	290	.303	- 6.64						
	2000			35	88		0		0	18.7	9.2	228	289	.492	- 7.24						
	2100			48	94		21		0	18.7	9.8	228	296	.946	- 7.74						
	2200	0		41	98		31		0	17.2	9.3	229	294	1.35	- 8.24						
	2300			47	89		0		0	17.1	9.1	229	295	1.20	- 8.64						
	2400			51	90		0		0	15.7	9.2	225	289	1.03	- 8.94						
3-30-75	0100			26	85		0		0	15.9	9.0	228	292	1.05	- 9.14						
	0200			55	103		0		2	13.6	7.4	288	227	1.03	- 9.44						
	0300			41	82		0		0	13.2	6.8	223	284	1.20	- 9.64						
	0400			27	82		0		0	12.6	6.9	227	288	1.59	-10.0						
	0500			48	84		0		0	10.6	6.7	219	284	1.29	- 9.94						
	0600			27	81		0		0	12.3	6.8	225	289	1.44	- 9.64						
	0700			55	86		0		0	12.1	7.9	220	282	.732	- 7.70						
	0800			54	86		0		2	10.7	6.6	220	282	- .221	- 6.40						
	0900			30	80		0		2	9.1	6.0	200	272	- .171	- 5.70						
	1000			56	89		0		2	12.5	8.3	205	268	- .393	- 5.20						
	1100	0		68	50		0		2	14.6	9.2	205	402	- .147	- 4.10						
	1200			77	60		0		2	15.7	9.4	201	263	- .186	- 2.70						
	1300			76	58		0		0	13.7	10.2	203	272	- .264	- 2.60						
	1400			37	63	51	0		0	14.5	9.9	205	267	- .299	- .600						
	1500			42	58	31	0		0	13.8	9.3	204	268	- .683	- .500						
	1600			31		65	0		0		7.8		292	- .820	1.30						
3-31-75	1000			47	71	37	3			10.7		145		- .167	7.60						
	1100			34	79	41	3			12.9		154		- .298	8.70						
	1200			35		31	3		4	14.7	8.0	159	226	-1.07	9.80						
	1300	0	0	31	18	44	3		7	13.8	8.5	168	233	-1.39	9.90						
	1400	0		38	43	35	5		9	13.7	7.5	167	236	-1.54	8.70						
	1500	0		50	44	39	10		9	13.6	7.0	155	240	- .586	5.70						
	1600	0	8	55	44	48	3		14	12.4	7.5	202	280	- .275	1.70						
	1700	28	8	38	81	52	141		14	14.0	10.2	225	294	- .151	- 1.64						
	1800	12	5	60	64	48	47		9	19.4	11.4	209	314	- .179	- 2.84						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°K)		[illegible] GAS (m³/sec.)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
3-31-75 (cont.)	1900	0	3	51	42	38	8		7	18.9	12.1	250	317	0.00	- 3.14						
	2000	0	0	62	38	33	5		9	19.4	13.1	251	318	0.00	- 3.44						
	2100	0	3	63	47	33	8		11	17.2	16.4	254	319	0.00	- 3.54						
	2200	0	13	86	48	35	18		18	17.4	10.4	256	322	0.00	- 4.14						
	2300	0	105	118	47	43	18		16	16.9	9.5	263	326	.0815	- 5.14						
	2400	0	50	90	43	42	8		14	17.0	8.8	269	328	.205	- 5.94						
4-01-75	0100	0	60	38	42	41	3		11	14.7	8.8	174	332	.0270	- 7.14						
	0200	0	34	47	43	35	3		11	17.2	9.2	271	330	.0893	- 7.84						
	0300	0	8	64	37	42	3		11	16.4	6.8	277	337	.796	- 8.54						
	0400	0	3	46	35	42	3		11	13.2	6.4	277	337	.903	- 8.84						
	0500	0	5	65	39	42	3		14	13.2	5.6	273	338	1.65	- 8.64						
	0600	0	5	64	39	44	3		12	14.2	6.1	275	393	1.20	- 8.84						
	0700	0	5	44	42	46	3		9	15.0	6.5	275	339	.839	- 9.04						
	0800	0	5	46	41	43	3		11	16.0	5.4	286	348	- .471	- 8.66						
	0900	0	5	47	44	48	3		9	14.8	6.2	292	356	- .791	- 8.26						
	1000	0	5	41	41	43	3		14	14.3	6.1	292	357	0.00	- 8.16						
	1100	0	8	31	68	47	5		9	15.0	7.8	303	369	0.00	- 7.34						
	1200		8	44	67	72	13		11	14.3	6.2	298	364	0.00	- 6.94						
	1300		10	37	37	60	8		7	13.3	6.5	296	356	0.00	- 6.84						
	1400		10	8	21	43	13		10	15.8	6.2	289	309	0.00	- 6.94						
	1500		5	26	13	43	10		7	16.5	6.4	296	361	0.00	- 6.84						
	1600		3	14	9	31	8		9	16.4	7.4	307	368	0.00	- 8.04						
	1700		5	31	21	34	8		12	15.0	7.8	306	370	0.00	- 8.04						
	1800		3	35	20	35	10		7	12.8	6.6	303	363	0.00	- 7.84						
	1900		5	25	21	34	10		9	12.7	6.5	300	365	0.00	- 7.84						
	2000		5	29	24	38	13		10	13.1	6.6	292	363	0.00	- 8.04						
	2100		3	22	14	29	13		9	13.4	5.2	279	348	0.00	- 8.24						
	2200		3	12	17	30	10		9	13.6	4.9	281	347	0.00	- 8.54						
	2300		0	29	5	30	10		9	13.2	5.0	288	354	0.00	- 8.54						
	2400		3	13	14	27	8		9	11.2	5.0	293	353	0.00	- 8.64						
4-02-75	0100		0	10	12	33	10		12	13.4	5.2	291	353	0.00	- 8.94						
	0200		3	35	5	29	10		5	13.4	5.3	290	353	0.00	- 8.94						
	0300		3	1	9	31	10		7	13.4	5.3	290	356	0.00	- 8.84						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gr/sec.)		TEMP. OF EXHAUST GASES (°K)		VOL. [illegible] GAS (m³/sec.)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
4-02-75 (cont.)	0400		3	26	7	37	10		9	13.6	4.8	289	415	0.00	- 8.94						
	0500		3	24	8	0	10		9	9.1	4.2	294	353	0.00	- 8.84						
	0600		5	13	10	38	13		11	10.1	4.5	287	347	0.00	- 9.04						
	0700		5	27	10	38	13		11	12.0	4.2	290	350	0.00	- 9.14						
	0800		5	38	13	41	13		9	11.0	4.9	283	335	0.00	- 8.74						
	0900		5	13	12	42	13		11	17.2	5.5	280	342	0.00	- 8.54						
	1000		5	14	13		13		4	10.9	4.9	286	350	0.00	- 7.94						
	1100		3	59	14	37	13		4	12.4	4.8	280	346	0.00	- 7.84						
	1200		3	38	17	47	13	60	4	13.2	5.8	279	343	0.00	- 5.10						
	1300		13	30	25	43	13	42	4	12.5	6.6	270	500	0.00	- 5.00						
	1400		18	31	22	46	10	47	4	14.4	8.3	265	322	0.00	- 4.40						
	1500		76	27	18	48	13	52	7	19.1	9.9	263	331	0.00	- 3.90						
	1600		21	34	22	54	10	54	7	24.1	10.5	268	331	0.00	- 3.40						
	1700		196	59	22	47	10	55	792	22.8	11.2	265	328	0.00	- 3.10						
	1800		257	44	22	52	10	54	4	21.7	10.3	262	327	0.00	- 3.80						
	1900		21	34	24	47	10	348	4	20.1	10.3	253	322	0.00	- 4.30						
	2000		10	35	25	43	13	82	14	17.2	10.1	248	316	.119	- 6.24						
	2100		10	35	26	44	10	123	16	16.5	9.7	245	313	.252	- 7.04						
	2200		8	26	352	46	60	46	9	15.8	8.3	240	317	.796	- 8.34						
	2300		3	43	513	41	277	43	4	13.1	7.2	238	299	1.10	- 9.34						
	2400		3	82	195	31	149	26	2	13.6	7.4	232	298	1.18	- 9.74						
4-03-75	0100		0	97	18	37	5	22	10	13.8	7.9	228	294	.903	-10.1						
	0200		0	86	14	26	8	22	4	11.6	6.7	224	289	1.44	-11.2						
	0300		0	84	12	39	3	24	7	10.4	7.1	219	295	1.86	-12.1						
	0400		0	64	10	44	3	24	4	10.2	6.6	216	293	2.18	-11.4						
	0500		0	35	13	33	3	24						2.14	-12.3						
	0600		0	42	18	29	3	21						2.14	-12.5						
	0700		5	46	9	21	0	4						2.28	-12.6						
	0800		3	26	10	30	0							- .422	-11.6						
	0900		0	60	13	34	52	140	4	5.9	5.0	205	293	-1.29	- 9.50						
	1000	400	3	94		22	559	51	4	8.3	5.7	237	308	- .946	- 7.60						
	1100	277	8	9		27	414	105	14	6.8	5.1	230	304	-1.99	- 6.00						
	1200		5	21	41	34	257	60	7	5.5	3.9	220	303	-1.76	- 4.20						
	1300		8	16	0	109	37	51	4	8.2	6.3	213	282	-1.97	- 3.00						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO$_2$ READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO$_2$ EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°C)		VOL. [illegible] GAS (m^3/sec.)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
4-03-75 (cont.)	1400		13	10	16	0	5	56	4	6.7	5.5	209	287	-2.01	- 1.90						
	1500	0	10	13	39	97	26	80	7	4.8	5.0	200	295	-2.07	- 1.90						
	1600	0	10	21	31	103	10	67	9	4.5	4.4	193	285	-2.14	- 1.70						
	1700	0	10	7	33	188	8	63	9	5.1	4.5	188	300	-1.80	- 1.70						
	1800	0	13	18	31	63	18	59	7	4.1	4.2	204	248	-1.92	- 1.60						
	1900	17	16	16	55	55	107	58	7	3.1	2.3	240	307	.906	- 2.60						
	2000	33	18	43	203	55	42	69	4	2.1	2.4	245	299	2.54	- 3.40						
	2100	0	13	48	60	38	16	58	0		1.2	131	310	2.59	- 5.76						
	2200		8	14	26	42	8	7	0	1.5			1037	2.59	- 4.90						
4-10-75																					
	0300		3	38	12	29	3	0	4	6.0	1.8	296	342	0.00	- 2.24						
	0400		0	38	9	31	3	1	7	6.0	1.8	286	350	0.00	- 2.46						
	0500		0	41	4	0	0	4	7	5.2	2.1	279	285	0.00	- 2.36						
	0600		5	96	24	42	8	3	11	7.7	3.7	270	385	0.00	- 2.36						
	0700		3	71	9	43	5	18	11	8.8	3.0	272	335	0.00	- 2.24						
	0800		10	68	9	51	5	20	7	9.0	4.8	267	328	0.00	- 2.04						
	0900		65	71	12	56	8	24	9	9.9	5.5	263	314	0.00	- 1.94						
	1000	0	29	63	12	63	8	20	11	10.4	5.7	260	322	0.00	3.00						
	1100	0	29	63	12	69	10	43	11	11.1	5.8	258	324	0.00	- .943						
	1200	0	58	93	17	84	13	56	11	12.4	6.7	265	329	0.00	1.00						
	1300	0	31	81	22	79	16	72	14	13.2	7.7	262	326	0.00	1.60						
	1400	0	58	54	17	77	16	127	11	13.1	7.6	259	323	0.00	- .143						
	1500	10	21	58	65	81	44	90	9	10.2	4.9	253	324	0.00	.900						
	1600	0	31	56	18	82	16	90	9	12.1	6.6	256	323	0.00	1.00						
	1700	0	73	71	20	84	16	82	11	13.8	6.8	259	326	0.00	1.20						
	1800	0	26	81	27	88	24	98	9	13.2	7.8	261	325	0.00	- .243						
	1900	0	81	92	18	88	18	80	14	11.9	7.2	262	278	0.00	- .243						
	2000	0	73	71	24	85	18	92	7	8.5	5.1	265	322	0.00	1.50						
	2100	0	52	55	14	81	16	84	11	8.7	3.8	264	330	0.00	.700						
	2200	0	31	44	17	81	13	97	9	7.6	4.0	253	319	0.00	- .100						
	2300	0	24	43	16	79	16	89	7	5.4	3.6	242	321	1.46	- .400						
	2400	4	21	52	39	72	26	82	7	7.2	3.7	234	301	1.50	- 2.14						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO$_2$ READINGS ($\mu g/m^3$)								HOURLY WIND SPEED PDGS (mph)		HOURLY WIND DIR. PDGS (°from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO$_2$ EMISSION RATE (gr/sec.)		TEMP. OF EXHAUST GASES (°C)		VOL. [illegible] GAS ([illegible]/sec.)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
4-11-75	0100	2	10	43	96	75	37	65	7	8.8	4.3	236	304	2.53	- 2.44						
	0200	0	10	33	44	67	16	72	7	7.9	4.2	237	306	2.51	- 2.84						
	0300	0	10	34	64	72	21	63	2	7.4	4.2	239	302	2.51	- 3.04						
	0400	4	10	41	120	68	26	71	4	6.0	4.7	240	305	2.52	- 3.34						
	0500	0	10	63	93		24	55	7	5.9	4.2	240	312	2.52	- 1.50						
	0600	0	10	37	39		16	55	4	6.8	4.0	238	310	2.51	- 3.04						
	0700	0	10	67	29		10	39	4	5.4	3.4	200	299	- .691	- 2.00						
	0800		10	26	12		8	30	2	5.1	3.7	201	292	- .535	- .900						
	0900	0	10	44	20		21	34	7	7.3	5.9	218	296	- .927	.700						
	1000	75	10	46	110		165	54	4	7.5	6.6	237	300	-2.00	2.00						
	1100	21	10	54	151		94	171	4	7.3	5.9	242	312	-2.03	4.10						
	1200	7	5	47	115		34	209	9	8.6	5.6	246	319	-1.78	5.30						
	1300	22	13	59	68		60	73	14	7.3	5.2	228	286	-1.99	6.90						
	1400	2	13	33	18		86	69	14	8.6	9.8	214	283	-1.27	8.40						
	1500	0	10	8	14	55	24	60	14	9.1	6.5	218	284	-1.62	8.80						
	1600	0	10		10	16	0	62	14	11.9	8.2	222	294	-1.68	8.90						
	1700	0	10	3	27	0	21	68	14	11.8	8.3	236	304	- .791	8.00						
	1800	0	16	3	26	0	39	65	11	11.1	8.0	227	293	- .577	7.60						
	1900	2	13	3	21	0	58	56	7	10.5	8.3	229	299	.377	6.70						
	2000	0	16	4	21	0	47	67	11	12.7	8.1	230	299	1.49	4.30						
	2100	17	16	14	133	0	81	58	11	6.4	4.1	236	303	2.54	3.10						
	2200	0	10	7	72	0	37	22	4	3.2	2.0	221	293	2.53	1.70						
	2300		8	0	27	0	31	0	2	1.7	1.0	206	301	2.54	7.00						
	2400		0	0	16	0	24		2	2.7		188	292	2.53	5.00						
4-12-75	0100		0	24	5	0	18		0	3.8	2.3	189	285	2.52	.500						
	0200		0	0	3	0	13		0	2.5	1.7	191	302	2.53	- .100						
	0300		0	0	0	0	16		0	3.7	2.3	183	595	2.42	- .900						
	0400		0		3	0	16		0	3.2		187	477	2.51	- .500						
	0500			0	0	0	16		0	1.8	1.7	182	285	2.52	- .800						
	0600			0	0	0	18		0	3.2		179	274	2.52	- 1.20						
	0700				0	3	18		0	4.2		185	299	- .828	- 1.20						
	0800			0	0	5	16		2	1.7		195	243	- .672	- .200						
	0900		0	5	48	0	55		2	2.3	2.8	216	302	-1.60	1.50						
	1000	51	0	0	391	0	327	8	4	2.3	2.9	219	309	-2.12	3.00						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO$_2$ READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (°From North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO$_2$ EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°K)		VOL. OF FLUE GAS (m³/sec.)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
4-12-75 (cont.)	1100	22	3	12	27	3	126	26	7	3.0	3.9	220	304	-1.33	4.00						
	1200	0	3	8	0	25	34	43	7	6.8	5.9	218	278	-2.04	5.00						
	1300	0	3	13	5	42	26	58	9	5.6	4.9	207	283	-1.53	6.10						
	1400	0	3	10	3	90	29	63	9	7.6	5.1	204	396	-1.06	7.20						
	1500	0	5	13	5	80	31	75	9	6.5	4.1	210	280	- .956	8.60						
	1600	0	5	10	12	60	31	77	11	6.2	4.5	227	303	-2.02	9.10						
	1700	0	5	16	10	35	31	71	11	4.8	4.1	214	286	-2.02	8.20						
	1800	2	5	4	13	50	47	80	11	3.1	3.5	222	285	-1.33	9.50						
	1900	0	5	12	30	44	71	72	11	2.7		228	259	1.04	8.40						
	2000	2	13	12	44	25	58	94	14	2.2		303	160	2.59	7.40						
4-17-75	1700	0	3	48	75		21	123	32	13.6	9.3	134	193	- .140	26.9						
	1800	0	3	52	93		26	122	34	12.3	8.2	134	193	- .163	28.1						
	1900	0	0	69	106		21	105	39	14.8	9.3	163	237	.0461	21.8						
	2000	0	3	75	118		34	107	44	15.0	11.9	203	340	.989	15.6						
	2100	0	3	63	116		29	93	37	20.0	13.4	217	288	.375	13.4						
	2200	0	0	60	92		21	75	24	18.8	10.5	229	297	.229	11.9						
	2300	0		43	65		16	63	16	16.2	9.7	234	308	.260	10.3						
	2400			13	41		10	52	16	11.7	7.4	247	314	.410	8.86						
4-18-75	0100			18	26		5	54	11	6.5	4.0	207	307	0.00	8.06						
	0200			20	25		3	41	7	7.7	4.6	243	319	0.00	7.86						
	0300			10	16		0	47	7	7.4	3.9	242	328	0.00	6.94						
	0400			7	9		0	38	4	6.1	2.2	270	340	0.00	6.76						
	0500			12	5		0	41	4	10.0	3.6	279	338	0.00	6.46						
	0600			3	4		0	39	4	12.6	4.4	272	338	0.00	6.66						
	0700			10	3		0	44	4	7.5	3.5	283	344	0.00	6.76						
	0800			9	3		0	52	4	9.2	3.8	275	344	0.00	5.24						
	0900			9	0		0	39	124	9.9	3.6	286	354	0.00	5.06						
	1000			4	0		29	37	0	10.0	4.6	283	343	0.00	4.04						
	1100				2		257	43	0	11.8	6.3	271	333	0.00	3.94						
	1200				0	33	50	38	2	13.8	9.0	261	325	0.00	3.54						
	1300		0		22	31		35	4	15.9	8.9	261	277	0.00	4.16						
	1400	0	0		47	30	0	33	4	16.6	9.5	263	328	0.00	3.66						
	1500	0	13		52	31	10	34	4	18.4	11.0	261	313	0.00	3.04						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (°From North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASSES (°C)		[illegible] GAS [illegible]	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK
4-18-75 (cont.)	1600	0	3		51	26	10	195	4	17.0	9.8	251	320	0.00	2.14						
	1700	0	3		54	25	16	302	4	15.5	8.8	249	314	0.00	2.14						
	1800	0	0		52	24	16	35	4	15.1	10.6	241	308	0.00	2.14						
	1900	0	0		51	27	13	21	4	18.7	11.3	229	294	0.00	1.54						
	2000	0	3		47	24	13	25	4	17.8	10.6	222	291	0.00	1.54						
	2100	0	3		48	26	16	27	7	15.8	9.0	208	283	1.53	1.54						
	2200	0	3		48	22	18	31	4	10.4	6.9	194	263	1.97	1.86						
	2300	0	3		54	17	16	30	4	11.0	7.9	193	265	.393	2.86						
	2400	0	3		51	20	16	31	4	12.8	9.0	201	265	.174	2.96						
4-19-75														.397	2.96						
	0100	0	5		50	18	16	24	4	12.8	8.0	195	262	.452	1.86						
	0200	0	3		52	16	16	30	4	10.9	8.0	181	254	.499	1.26						
	0300	0	3		51	16	16	25	4	11.5	5.9	180	243	.397	1.16						
	0400		3		51	18	16	31	4	10.1	6.0	177	244	.397	.957						
	0500		3		56	110	18	20	4	11.1	6.1	175	239	.351	.557						
	0600		0		55	0	16	18	2	11.8	6.2	180	247	.166	.357						
	0700		0		52	13	16	13	2	12.4	8.6	174	254	-.0890	.857						
	0800		0		51	13	16	22	2	16.3	10.5	200	265	-.0578	1.46						
	0900		3		50	16	18	26	2	19.6	12.3	210	273	.00	2.76						
	1000		3		48	20	18	26	2	24.9	15.7	213	277	.00	3.46						
	1100		5		52	22	21	34	4	25.5	15.7	215	276	-.00717	4.56						
	1200		5		56	26	21	41	4	23.1	15.0	213	274	-.0773	4.56						
	1300		8		51		21	38	4	25.0	15.5	210	274	.00	3.86						
	1400		5		56	169	21	35	4	23.1	15.1	211	274	.00	4.46						
	1500		5		50	69	21	39	2	23.6	14.0	210	272	.00	4.36						
	1600		8		54	131	24	33	4	23.8	14.4	213	279	.00	4.16						
	1700		5		63	42	24	37	4	22.9	14.2	213	281	-.116	4.16						
	1800		5		58	33	18	34	4	21.4	13.1	217	283	-.171	3.96						
	1900		5		55	26	21	31	4	19.2	11.7	223	290	.159	3.96						
	2000		5		63	31	21	31	4	17.7	11.3	221	284	.174	3.66						
	2100		5		54	26	21	27	2	15.3	7.8	218	286	.452	3.56						
	2200		5		56	25	18	18	2	9.7	5.8	214	281	.839	3.36						
	2300		5		56	14	18	14	2	7.1	4.6	206	280	.989	3.16						
	2400		0		63	13	16	0	0	5.9	4.7	191	275	1.37	2.76						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES [illegible]		[illegible] GAS [illegible]	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
4-20-75	0100		0	64		3	13		0	5.0	3.2	189	282	1.86	3.20						
	0200		0	54		0	13		2	6.6	3.8	197	264	1.93	2.10						
	0300		0	52		0	10		2	5.3	3.5	187	283	1.76	1.70						
	0400			50			10		2	7.5	3.2	177	247	2.11	.600						
	0500			50			10		0	3.3	3.2	202	281	1.50	.100						
	0600			50			10		2	5.2	2.5	183	250	1.31	.400						
	0700			46			10		0	3.8	2.8	197	225	- .395	.600						
	0800			46			10		0	3.5	3.1	193	280	- .956	2.40						
	0900			46			16	1	2	5.1	5.3	187	249	- .810	4.40						
	1000		0	44			26	9	0	9.7	6.3	226	295	-1.72	5.50						
	1100		0	50			31	25	0	11.0	12.1	236	303	-1.87	7.10						
	1200		3	54			37	29	4	12.0	13.9	246	306	-1.64	8.30						
	1300		3	68			39	62	2	9.9	6.5	241	313	-1.56	9.30						
	1400	0	5	67			34	62	2	8.2	5.9	236	306	-1.62	9.70						
	1500	0	8	76			39	51	4	7.3	5.6	235	295	-1.85	10.9						
	1600		8	73			31	59	7	4.5	4.7	242	282	-2.52	10.2						
	1700	0	10	75			29	69	9	5.6	4.7	254	315	-1.72	10.9						
4-23-75	1300		0	22	12		31	69	14	7.1	4.8	145	202	- .878	17.6						
	1400	0	0	28	8		8	38	607	7.1	3.8	147	212	- .927	18.7						
	1500	0	3	37	7		0	39	21	4.5	3.7	178	260	- .907	19.2						
	1600	0	3	29	7		0	41	19	4.2	2.9	214	289	0.00	18.3						
	1700	0	3	39	5		0	37	19	4.5	2.6	293	332	0.00	18.3						
	1800	0	3	29	5		3	39	21	6.2	5.0	272	326	0.00	17.4						
	1900	0	3	42	7		3	39	21	11.1	4.5	278	343	0.00	16.8						
	2000	0	0	37	7		3	35	19	7.7	4.1	268	335	.428	15.3						
	2100	0	0	37	0		3	41	19	7.8	3.1	258	332	1.04	13.4						
	2200	0	0	31	0		0	35	14	6.2	2.7	269	341	.903	12.3						
	2300	0	0	12	0		0	33	16	5.7	3.8	253	326	.562	11.6						
	2400	0	0	8	0		0	27	14	3.5	2.9	261	334	1.35	12.9						
4-24-75	0100		0	20	0		0	24	11	7.4	4.3	270	335	0.00	12.7						
	0200	0	0	22	0		0	25	9	5.7	3.2	276	338	0.00	10.9						
	0300	0	0	13	0		0	27	9	4.2	3.5	260	334	0.00	10.7						
	0400	0	0	7	8		0	30	9	7.1	4.8	263	335	0.00	10.5						
	0500	0	0	38	10		0	30	11	3.4	1.5	282	346	0.00	10.3						
	0600	0	0	7	0		0	34	11	4.7	2.2	298	413	0.00	10.9						

Table 10 (cont)

TABULATION OF DATA COLLECTED (FOR DES MOINES, IOWA)

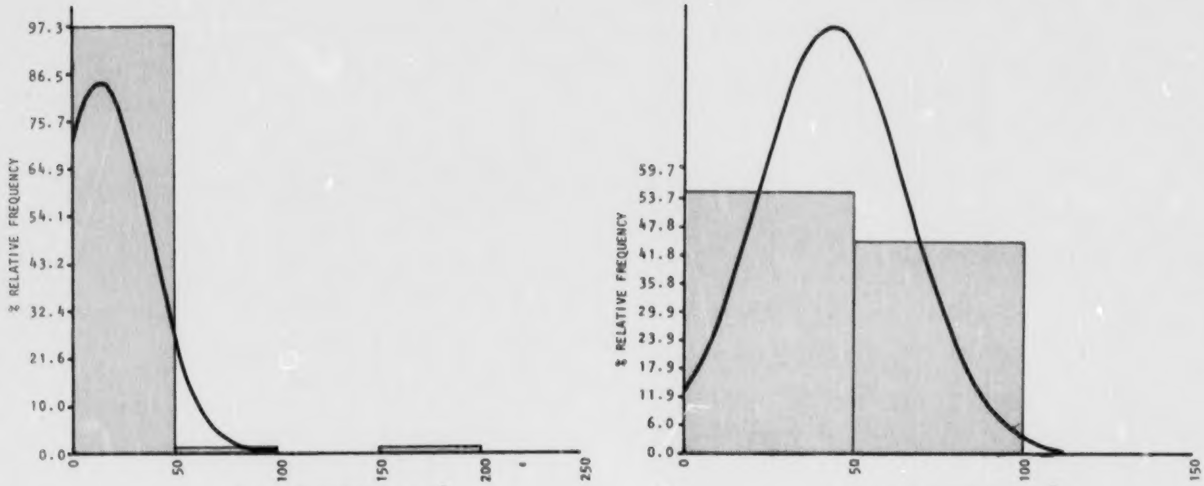
DATE	TIME	HOURLY SO_2 READINGS ($\mu g/m^3$)								HOURLY WIND SPEED RDGS (mph)		HOURLY WIND DIR. RDGS (° from North)		STABILITY NUMBER	EFFECTIVE STACK HEIGHT TEMPERATURE (°C)	SO_2 EMISSION RATE (gm/sec.)		TEMP. OF EXHAUST GASES (°K)		VOL. OF FLUE GAS (m³/sec)	
		#1	#2	#3	#4	#5	#6	#7	#8	#1	#8	#1	#8			STACK #1	STACK #2	STACK #1	STACK #2	STACK #1	STACK #2
4-30-75	1100	0				26	24	10		13.7		211		- .668	9.20						
	1200	0		7		92	18	20		14.2		206		- .911	10.9						
	1300			1	0		3	18		14.5		199		- .914	9.50						
	1400			8	4		0	22		14.4		202		- .635	8.60						
	1500			27	8	39	0	31		15.4		209		.00	8.50						
	1600			10	18	65	0	29		13.6		207		- .859	8.00						
	1700			17	13	13	0	29		14.1		217		- .917	8.60						
	1800			20	8	0	0	25		12.3		217		.743	10.6						
	1900			68	10	0	0	25		8.8		229		1.39	11.1						
	2000			22	9		0	33		4.7		231		2.53	9.30						

Table 11

SUMMARY OF AMBIENT SO_2 AIR MONITORING DATA

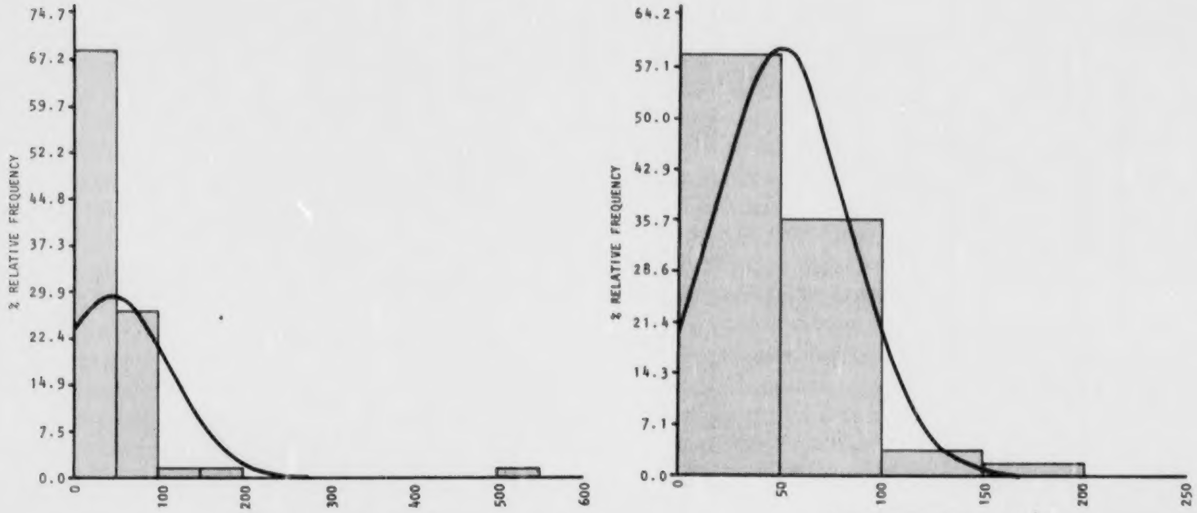
Site No.	Maximum 24-HR (ug/m^3)	2nd Highest 24-HR (ug/m^3)	Minimum 24-HR (ug/m^3)	Arithmetic Mean (ug/m^3)	No. of Values Exceeding Primary Standard	No. of Samples	Standard Deviation
Ames, Iowa							
1	248.0	207.9	0.0	79.3	0	72	45.2
2	172.9	147.6	0.0	62.6	0	79	46.8
3	136.9	122.1	0.0	30.2	0	65	43.7
4	302.8	133.7	0.0	35.9	0	45	51.6
5	141.3	106.4	0.3	27.5	0	61	26.4
6	196.3	150.6	0.0	35.8	0	32	53.1
7	120.7	102.4	0.0	26.7	0	63	32.4
8	515.6	336.0	0.0	100.9	1	74	73.6
Des Moines, Iowa							
1	159.8	121.8	0.0	10.2	0	84	24.8
2	190.3	53.1	0.8	14.2	0	74	23.6
3	90.2	85.0	0.7	43.5	0	67	22.1
4	527.4	199.2	0.0	45.1	1	50	68.3
5	189.8	139.3	0.8	50.4	0	56	33.4
6	97.8	80.3	0.1	22.0	0	76	18.6
7	204.8	202.3	12.6	65.6	0	75	37.5
8	57.7	55.7	0.7	16.5	0	67	12.6

FREQUENCY DISTRIBUTION OF SULFUR DIOXIDE CONCENTRATIONS



24-HOUR CONCENTRATION (µg/m^3)
SITE NO. 2, DES MIONES, IOWA

24-HOUR CONCENTRATION (µg/m^3)
SITE NO. 3, DES MIONES, IOWA



24-HOUR CONCENTRATION (µg/m^3)
SITE NO. 4, DES MIONES, IOWA

24-HOUR CONCENTRATION (µg/m^3)
SITE NO. 5, DES MOINES, IOWA

FIGURE 14

Figure 14

FREQUENCY DISTRIBUTION OF SULFUR DIOXIDE CONCENTRATIONS

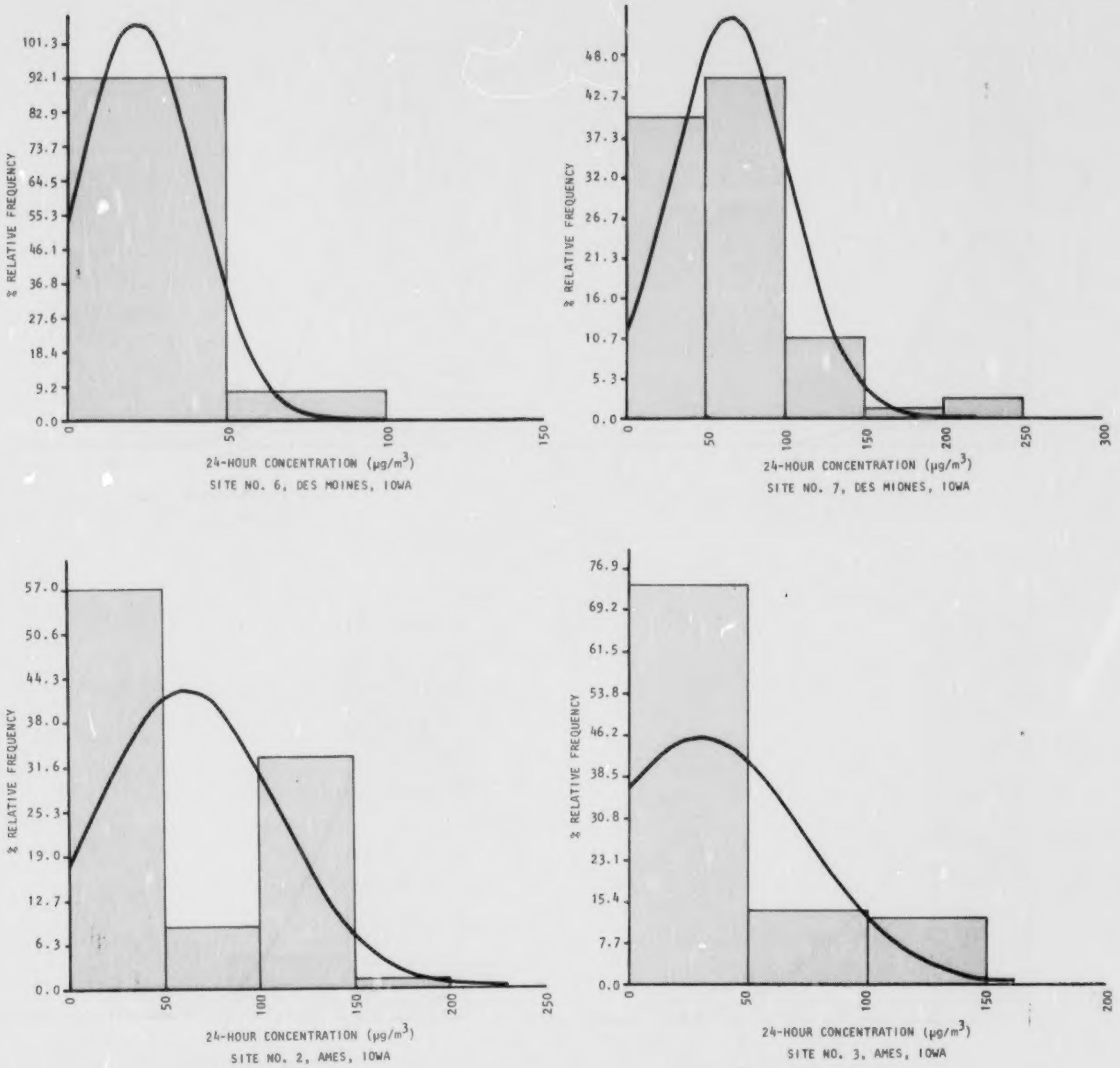
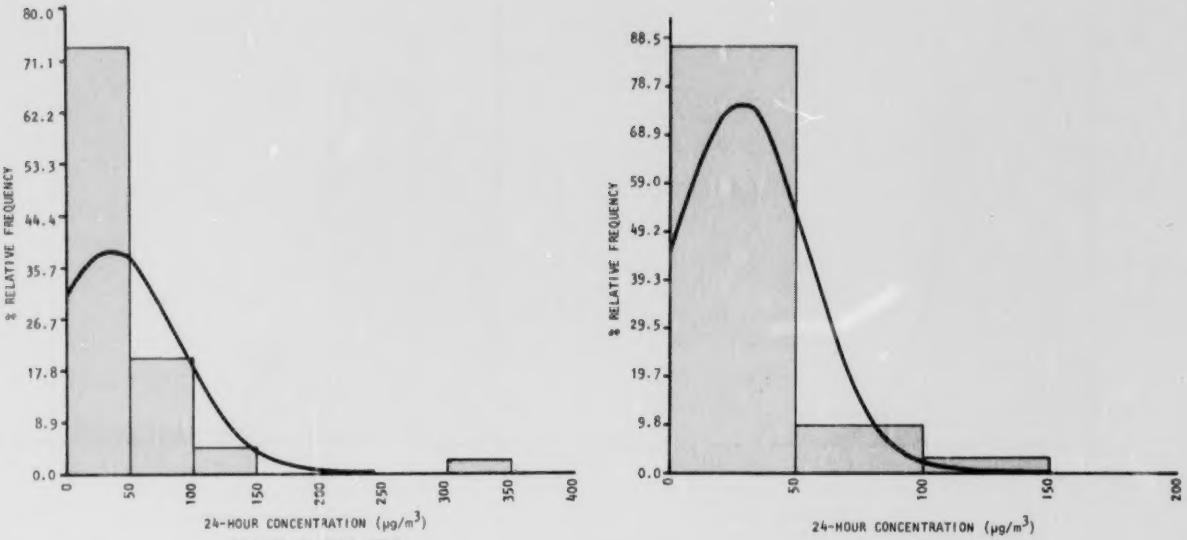


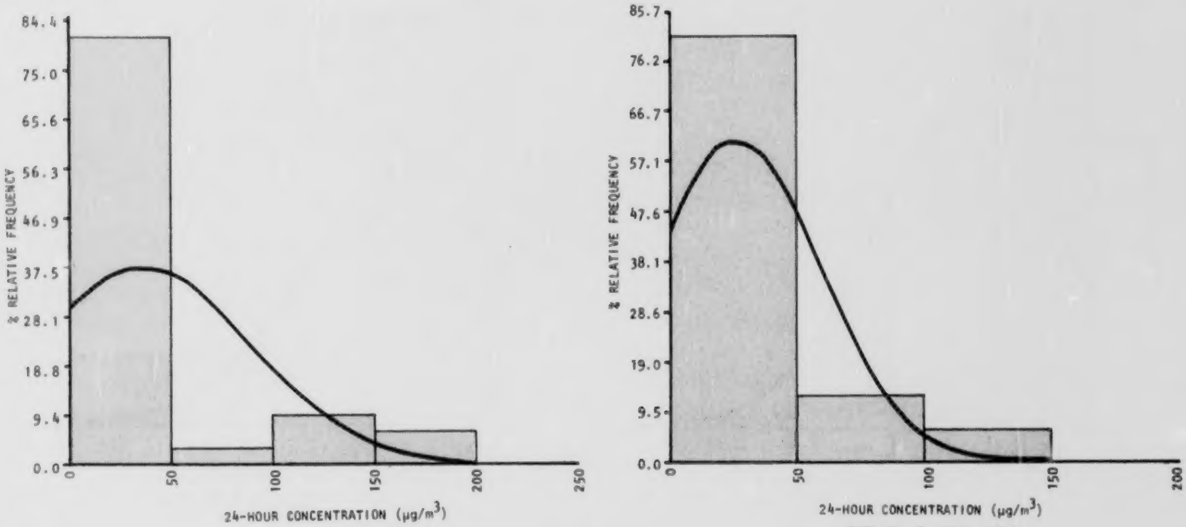
Figure 14 (cont.)

FREQUENCY DISTRIBUTION OF SULFUR DIOXIDE CONCENTRATIONS



SITE NO. 4, AMES, IOWA

SITE NO. 5, AMES, IOWA



SITE NO. 6, AMES, IOWA

SITE NO. 7, AMES, IOWA

Figure 14(cont.)

FREQUENCY DISTRIBUTION OF SULFUR DIOXIDE CONCENTRATIONS

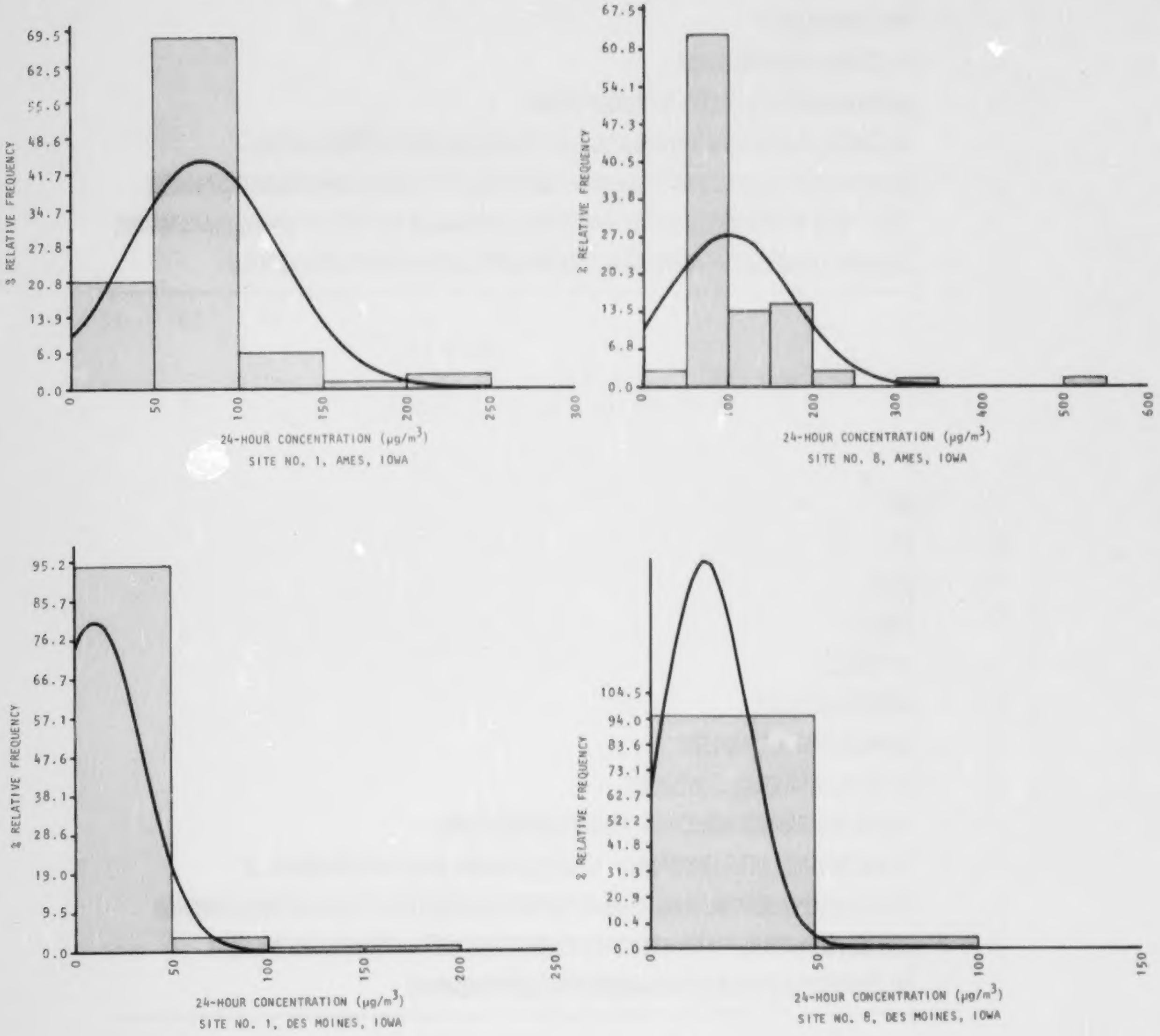


Figure 14(cont.)

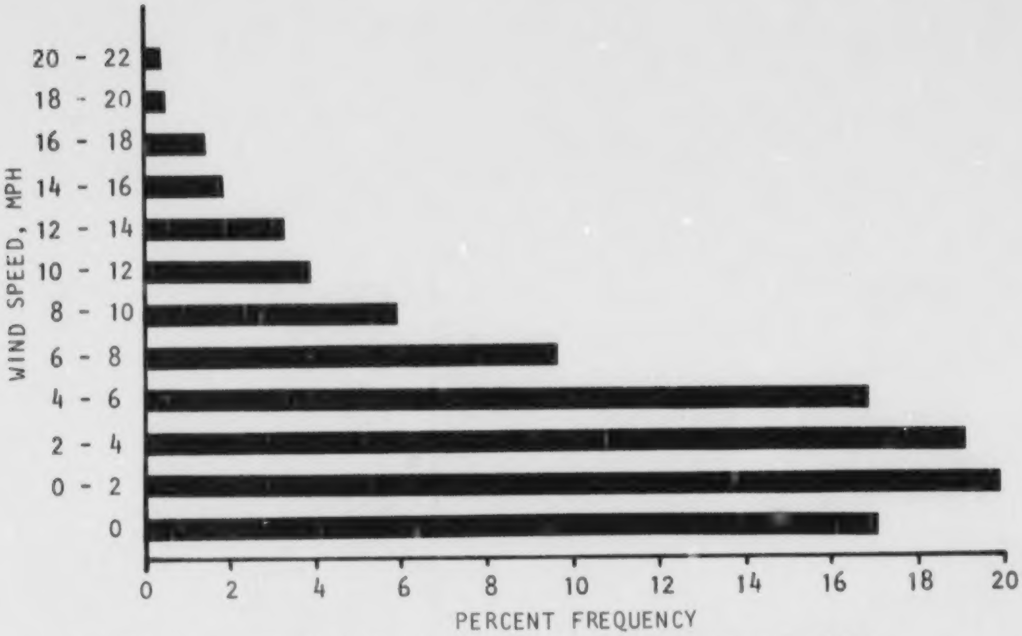


FIGURE 15 FREQUENCY DISTRIBUTION OF HOURLY WIND SPEED
SITE NO. 1, AMES, IOWA

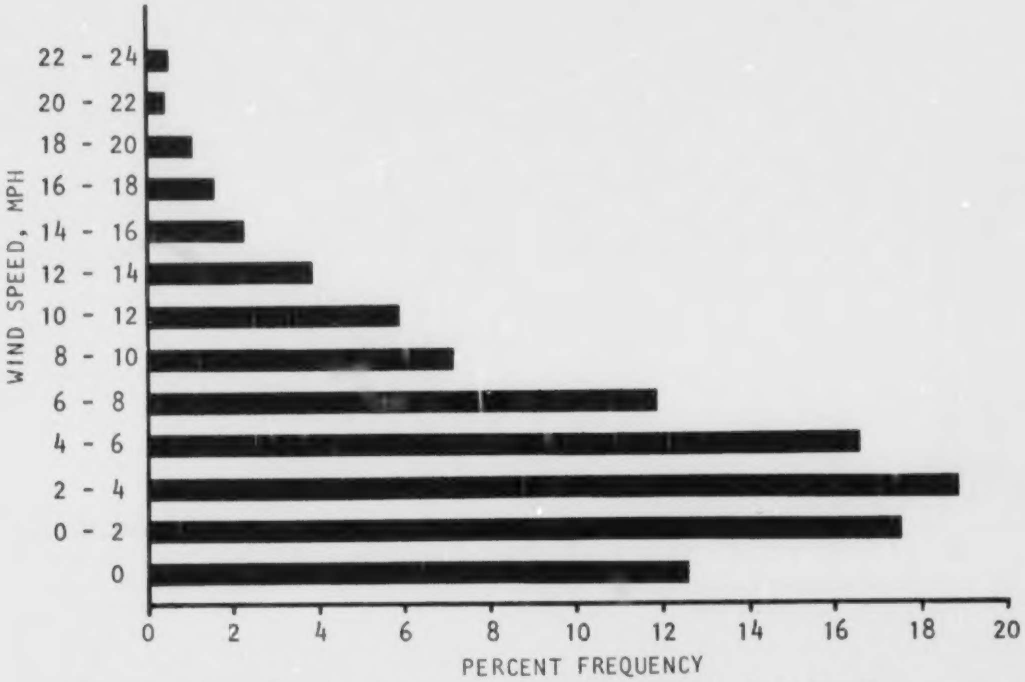


FIGURE 16 FREQUENCY DISTRIBUTION OF HOURLY WIND SPEED
SITE NO. 8, AMES, IOWA

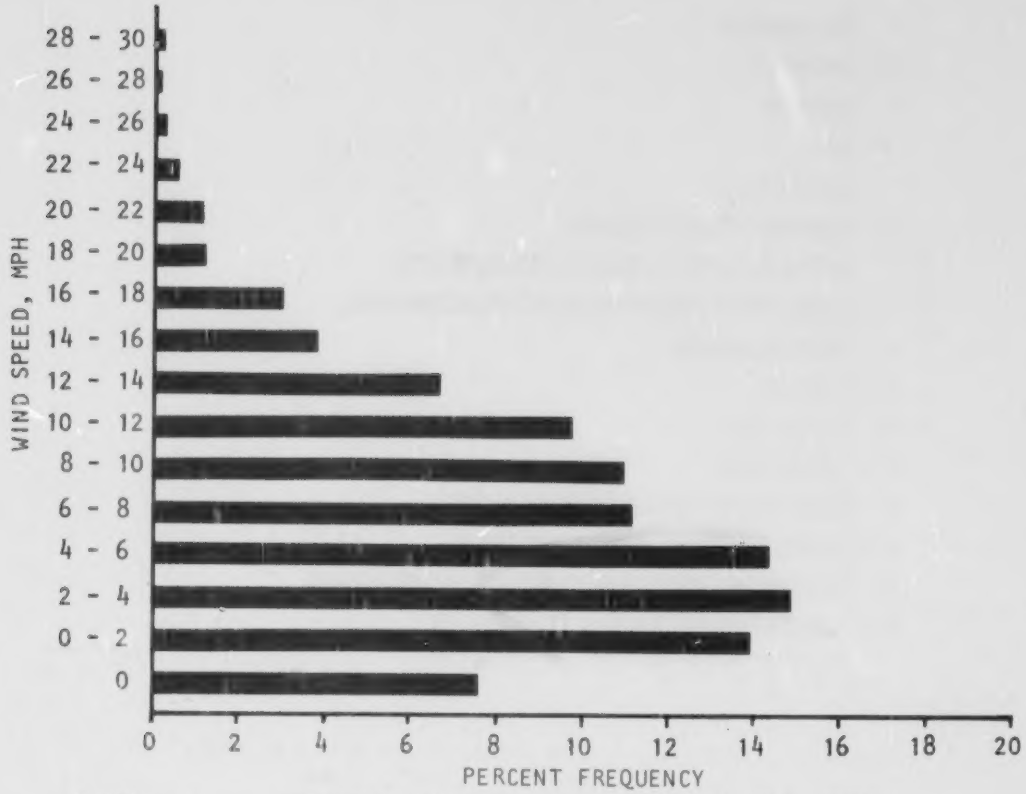


FIGURE 17 FREQUENCY DISTRIBUTION OF HOURLY WIND SPEED SITE NO. 1, DES MOINES, IOWA

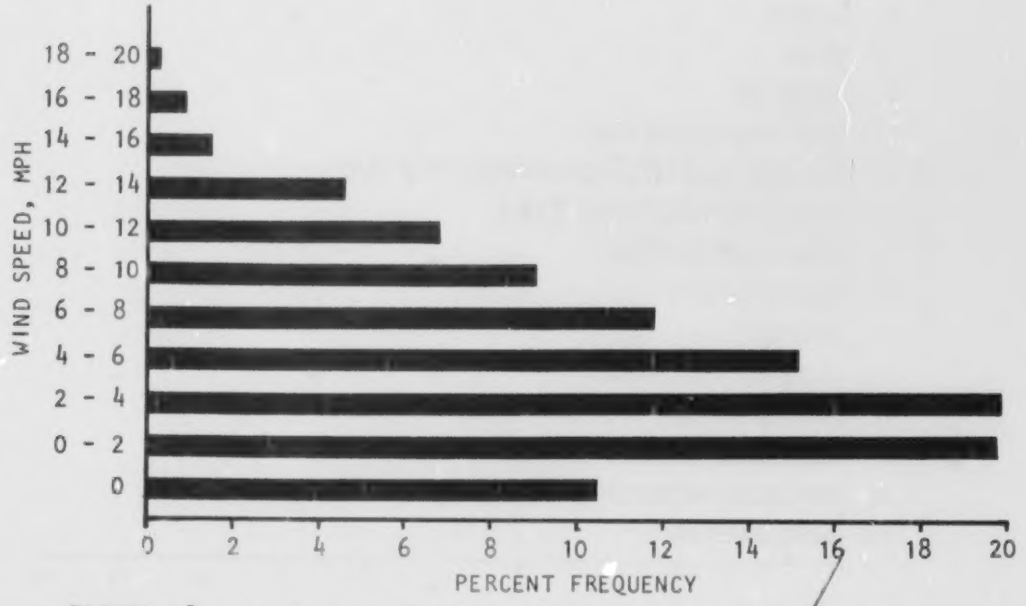


FIGURE 18 FREQUENCY DISTRIBUTION OF HOURLY WIND SPEED SITE NO. 8, DES MOINES, IOWA

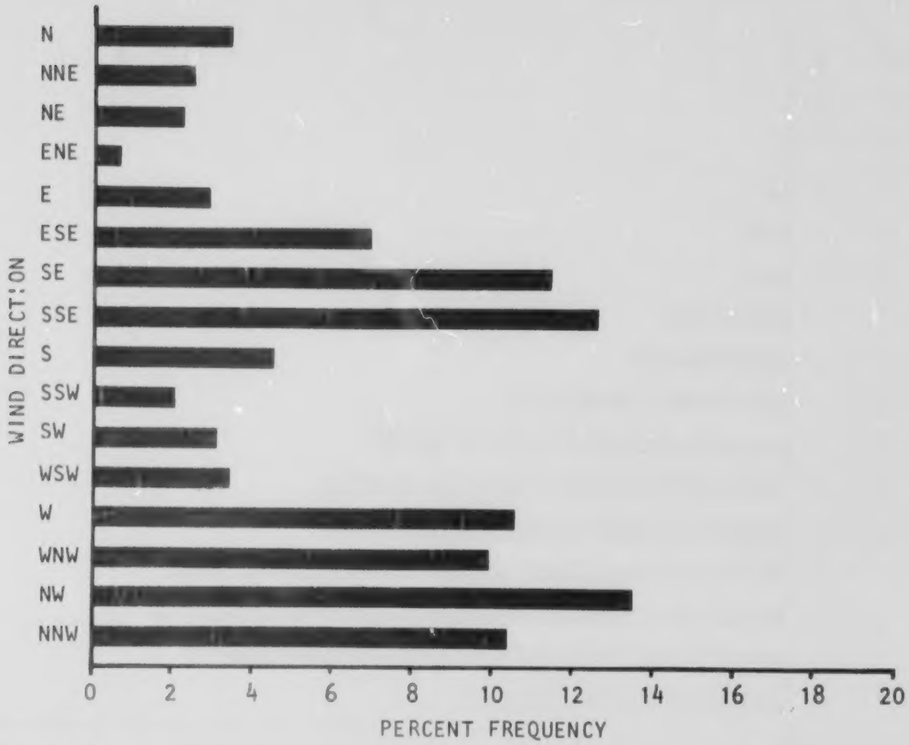


FIGURE 19 FREQUENCY DISTRIBUTION OF HOURLY WIND DIRECTION SITE NO. 1, AMES, IOWA

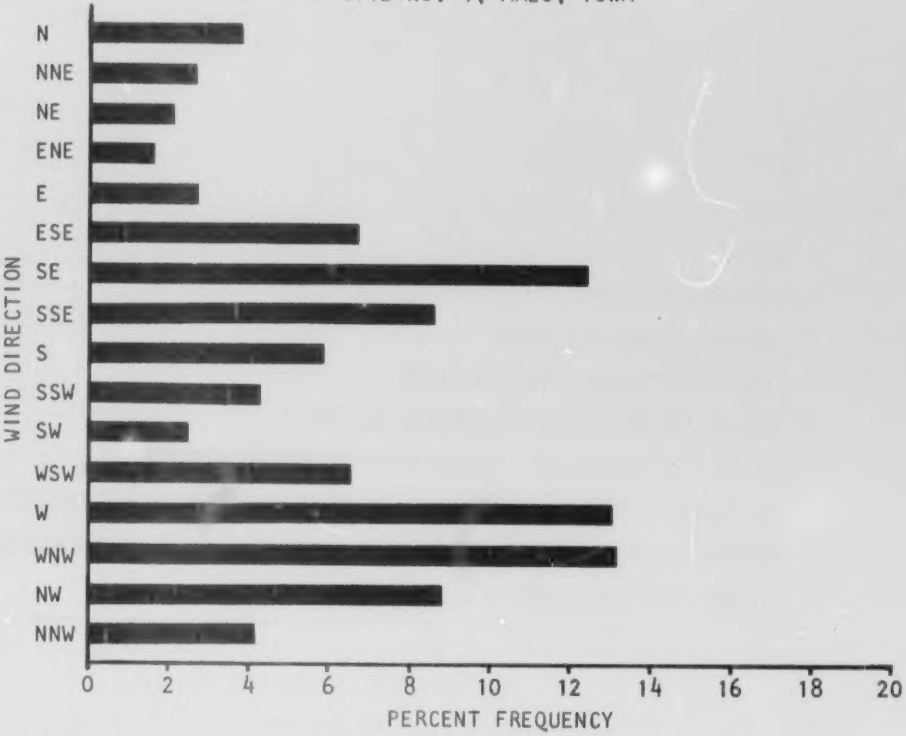


FIGURE 20 FREQUENCY DISTRIBUTION OF HOURLY WIND DIRECTION SITE NO. 8, AMES, IOWA

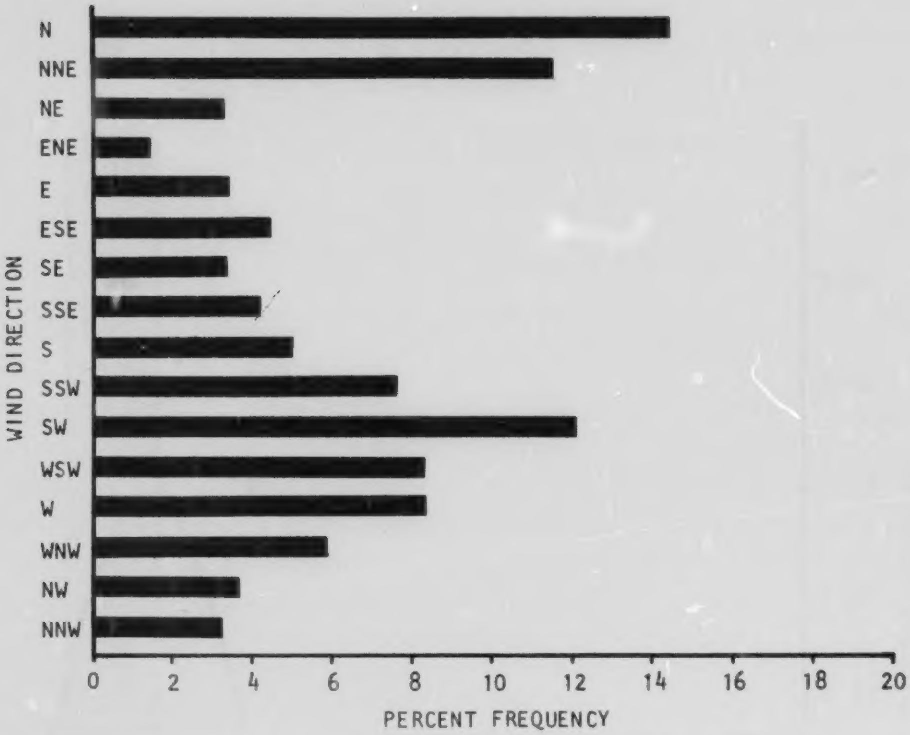


FIGURE 21 FREQUENCY DISTRIBUTION OF HOURLY WIND DIRECTION SITE NO. 1, DES MOINES, IOWA

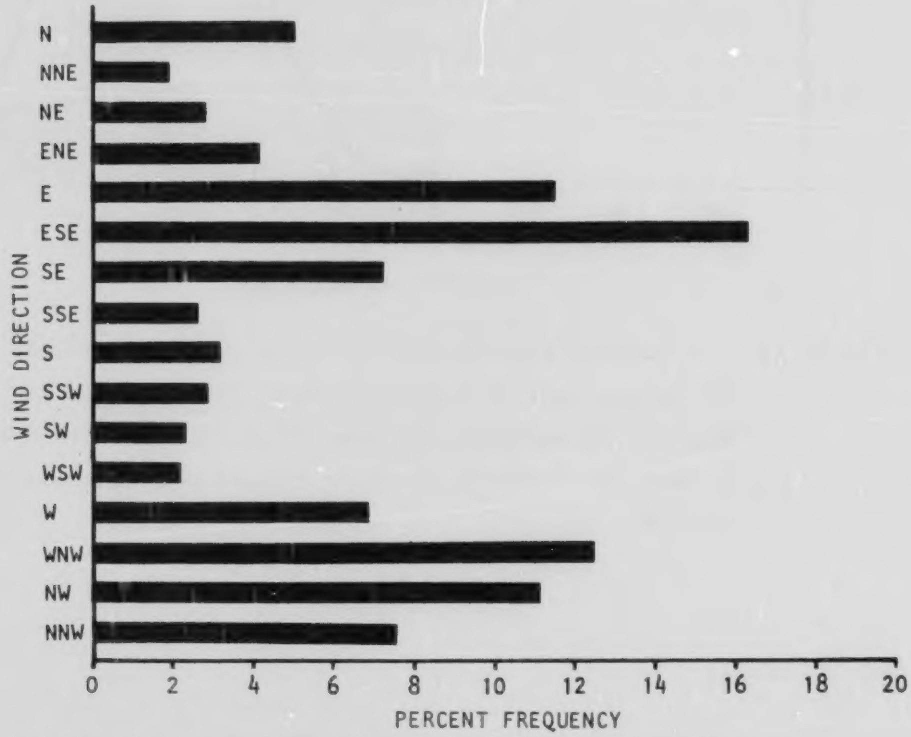


FIGURE 22 FREQUENCY DISTRIBUTION OF HOURLY WIND DIRECTION SITE NO. 8, DES MOINES, IOWA

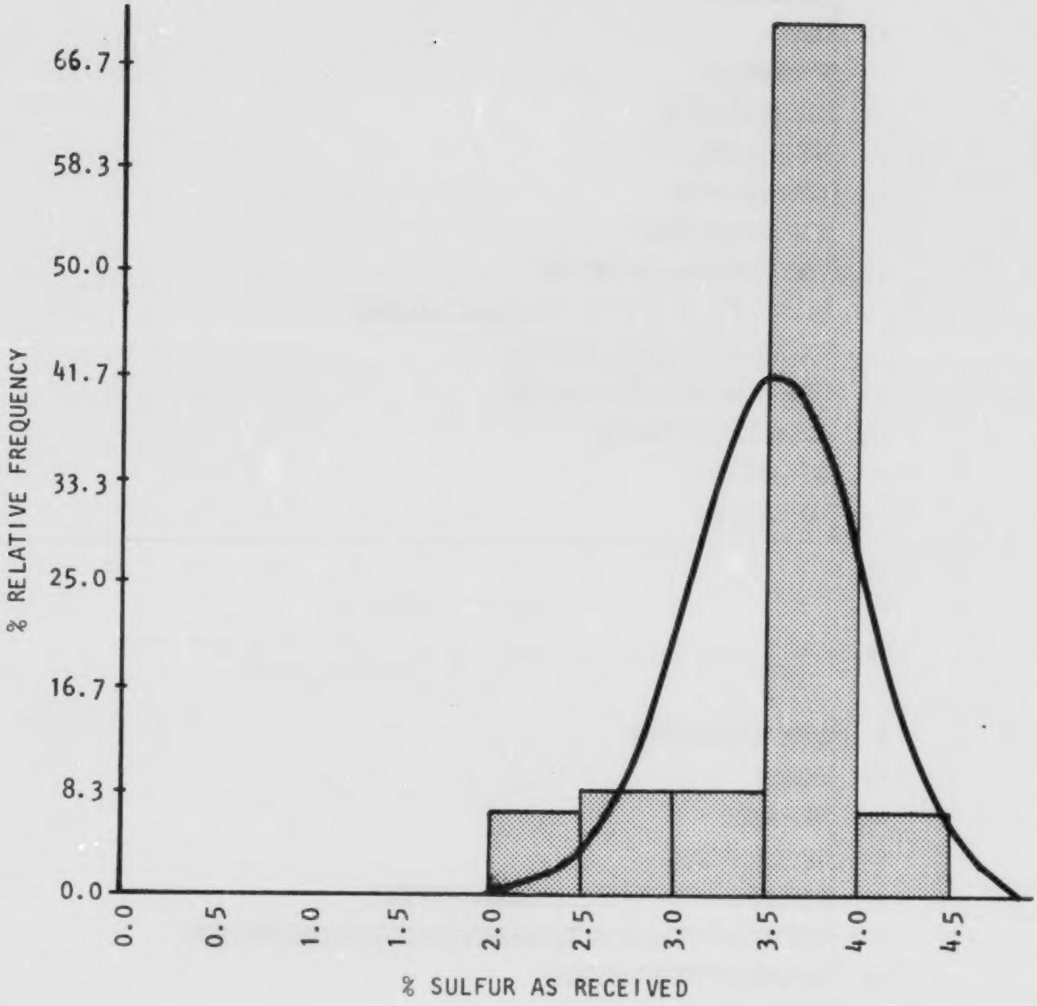


FIGURE 23 Frequency distribution of % sulfur, as received, for Kansas coal at Physical Plant, Ames, Iowa. Based on 60 samples, the mean value is 3.57 % sulfur, as received, and the standard deviation of the samples is 0.48.

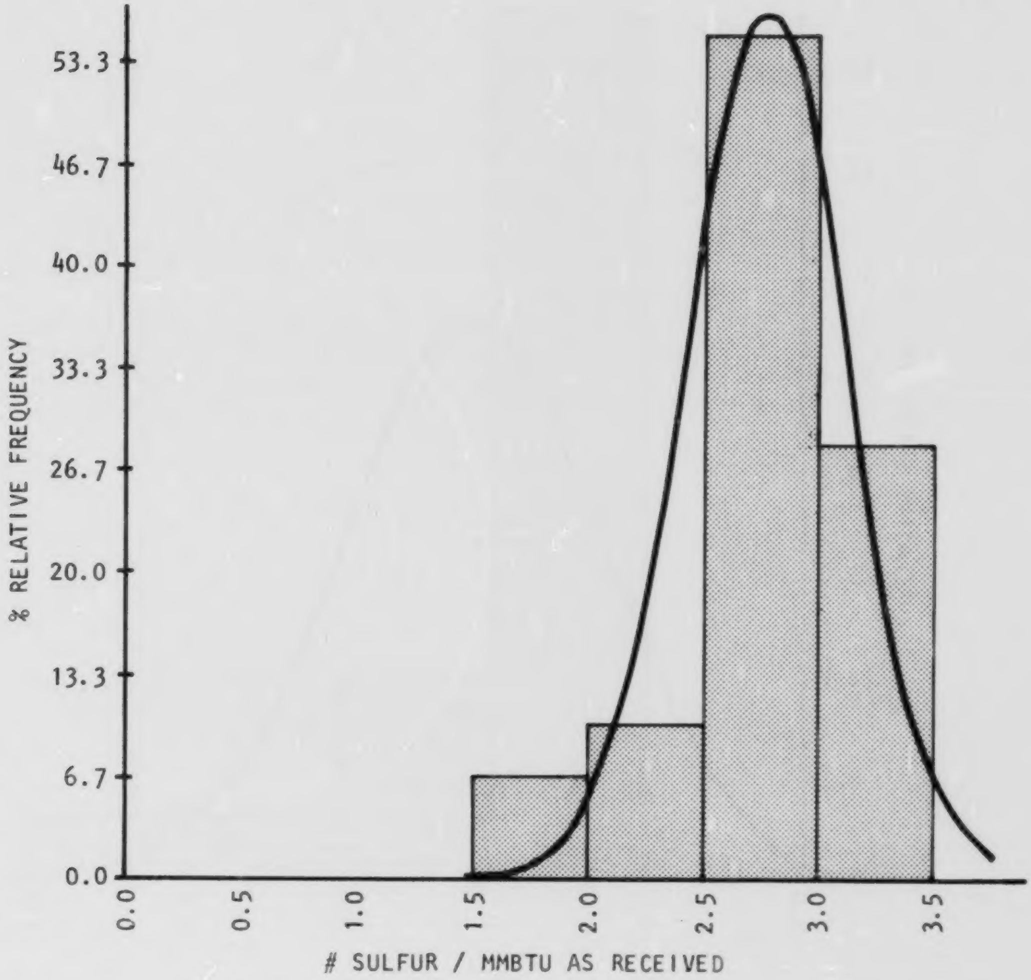


FIGURE 24 Frequency distribution of lbs. of sulfur per Million BTU, as received for Kansas coal at Physical Plant, Ames, Iowa. Based on 60 samples, the mean value is 2.78 # sulfur per MM BTU, as received, and the standard deviation is 0.35.

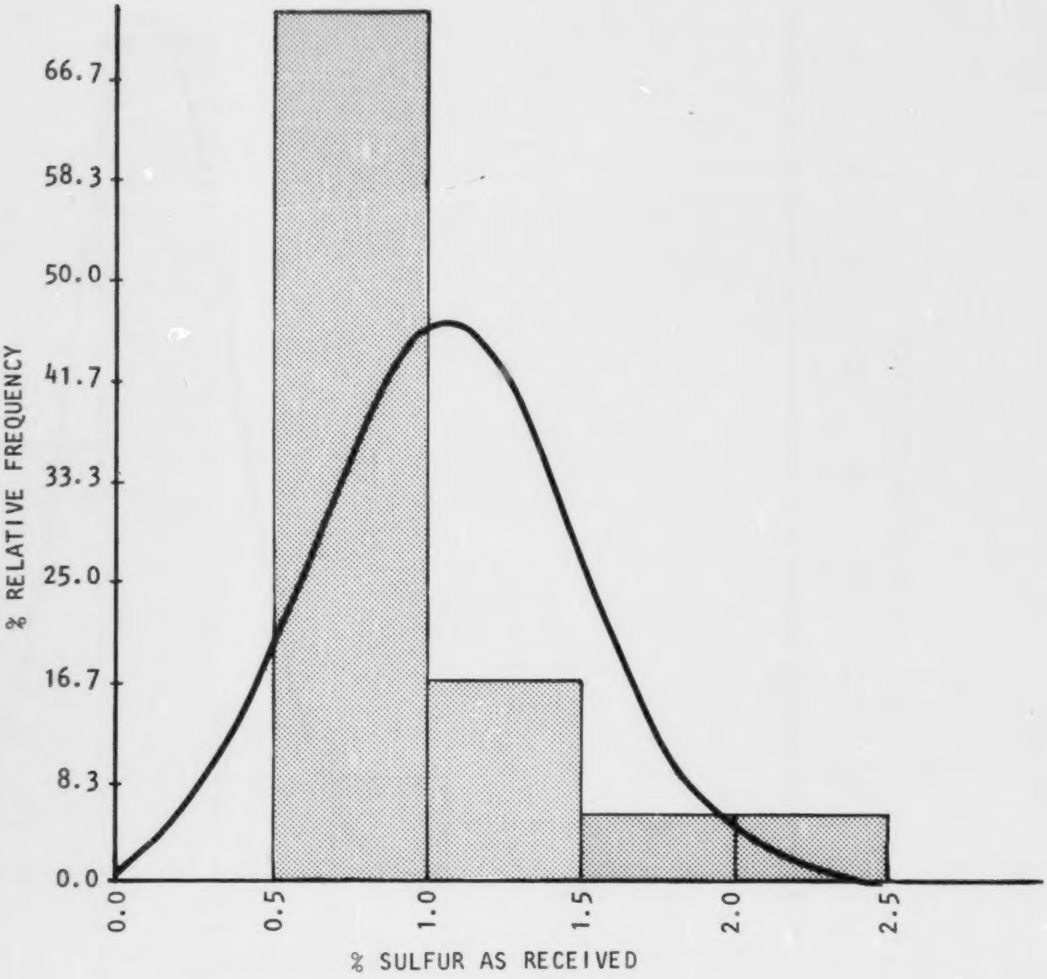


FIGURE 25 Frequency distribution of % sulfur, as received, for Wyoming coal at Physical Plant, Ames, Iowa. Based on 36 samples, the mean value is 1.06 % sulfur, as received, and the standard deviation of the samples is 0.42.

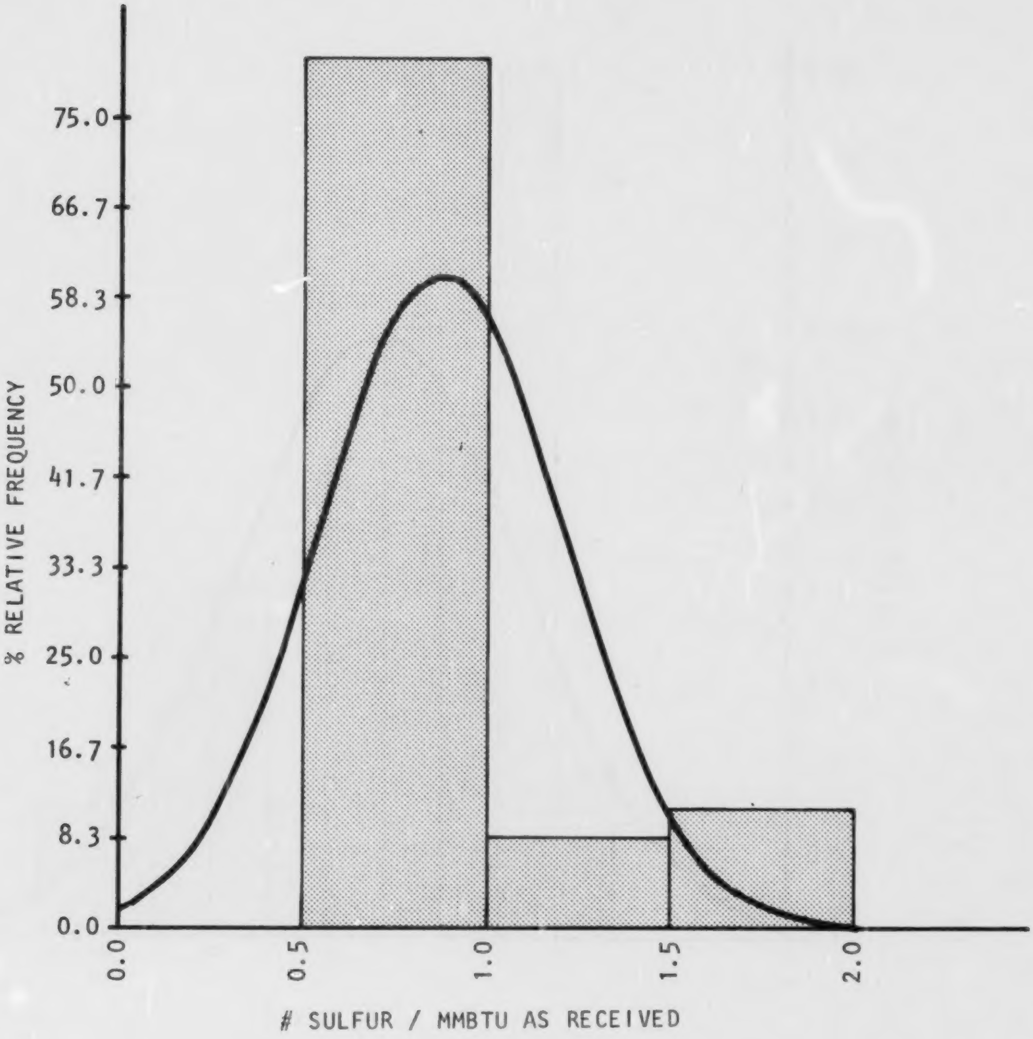


FIGURE 26 Frequency distribution of lbs. of sulfur per Million BTU, as received, for Wyoming coal at Physical Plant, Ames, Iowa. Based on 36 samples, the mean value is 0.88 # sulfur per MM BTU, as received, and the standard deviation of the samples is 0.33.

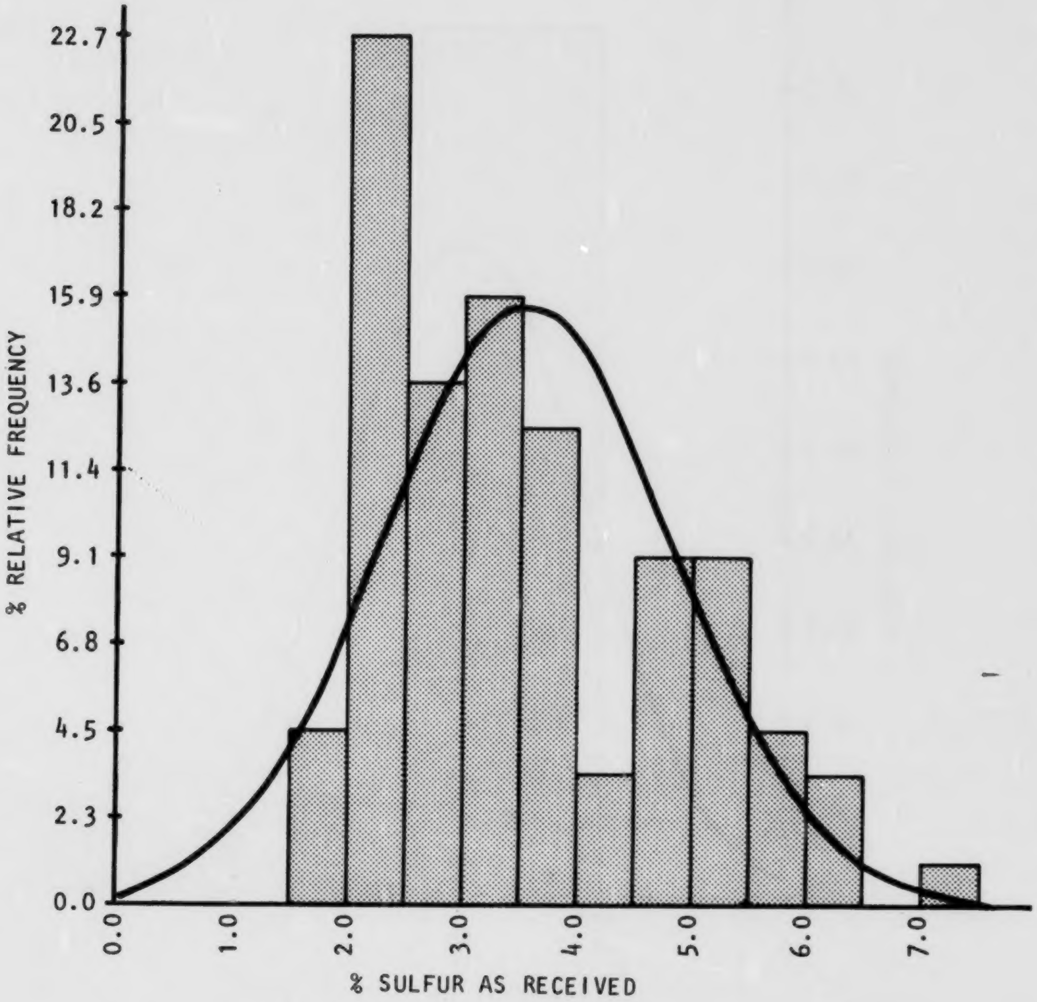


FIGURE 27 Frequency distribution of % sulfur, as received, for Unit No. 10, Iowa Power, Des Moines, Iowa. Based on 88 samples, the mean value is 3.57 % sulfur, as received, and the standard deviation is 1.26.

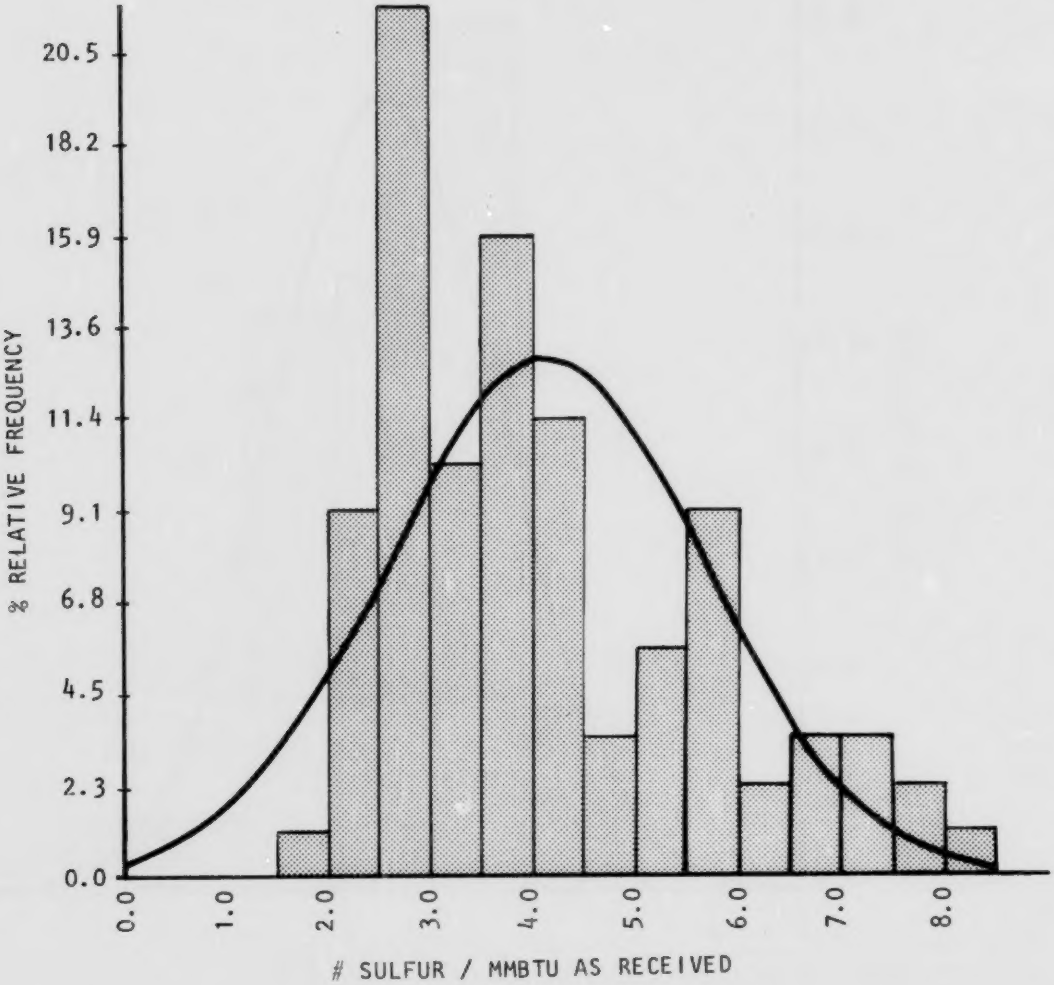


FIGURE 28 Frequency distribution of lbs. of sulfur per Million BTU, as received, for Unit No. 10, Iowa Power Des Moines, Iowa. Based on 88 samples, the mean value is 4.11 # sulfur per MM BTU, as received, and the standard deviation of the samples is 1.54.

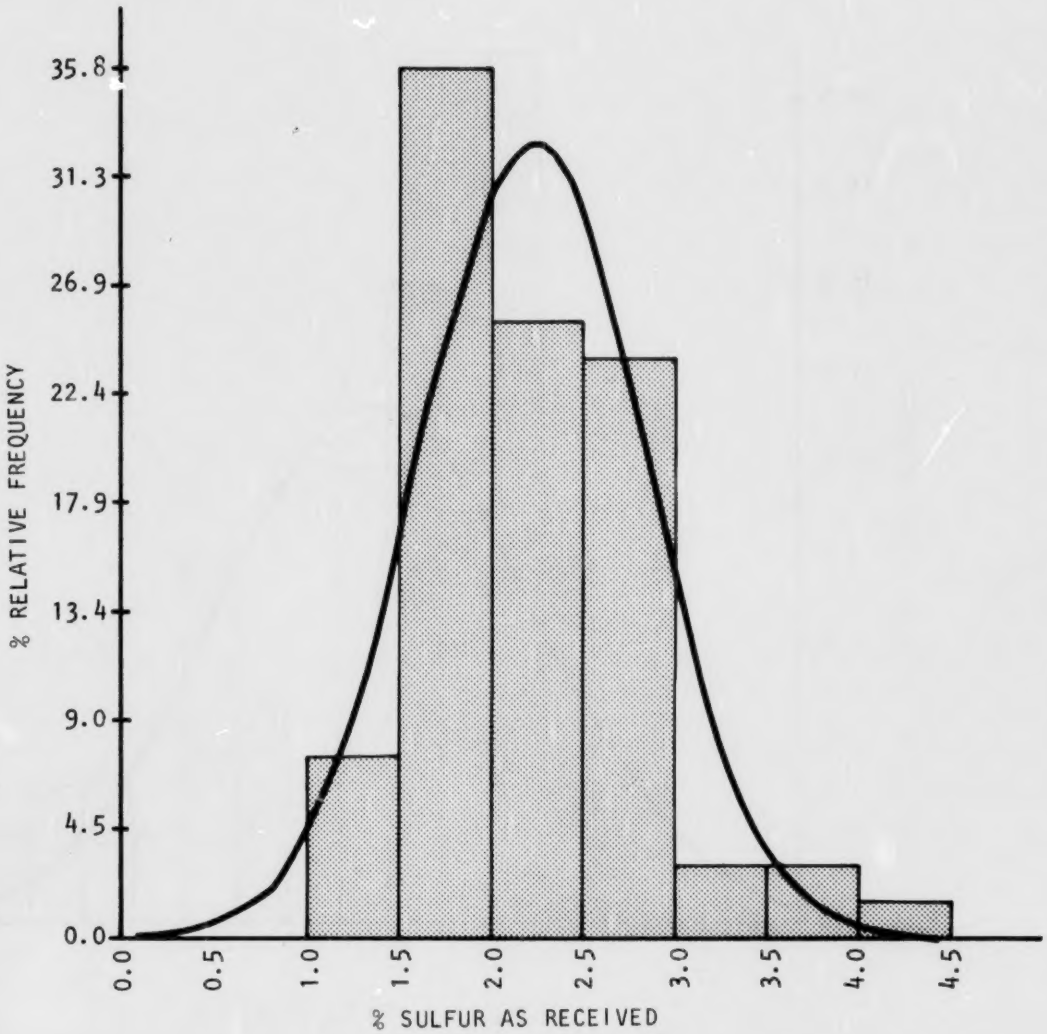


FIGURE 29 Frequency distribution of % sulfur, as received for Unit No. 11, Iowa Power, Des Moines, Iowa. Based on 67 samples, the mean value is 2.24 % Sulfur, as received, and the standard deviation is 0.61.

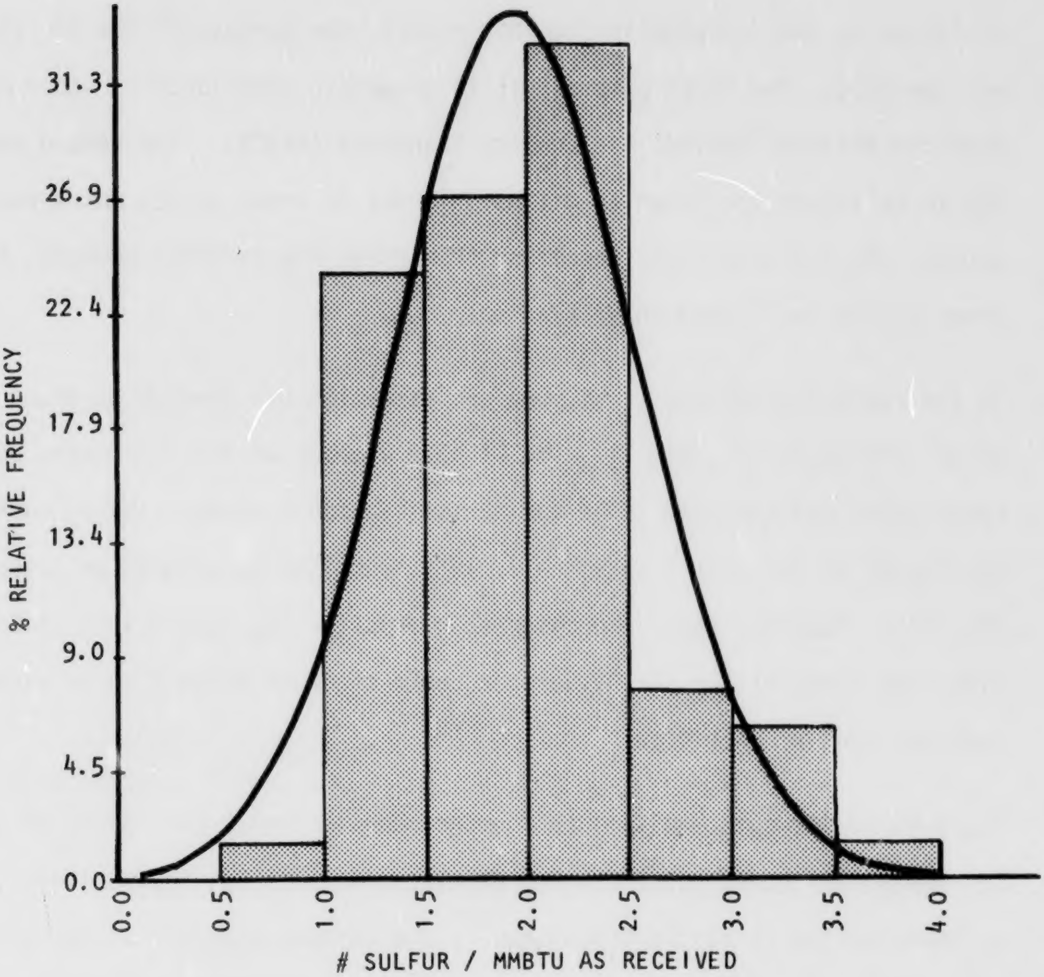


FIGURE 30 Frequency distribution of lbs. of sulfur per Million BTU, as received, for Unit No. 11, Iowa Power, Des Moines, Iowa. Based on 67 samples, the mean value is 1.94 # sulfur per MM BTU, as received, and the standard deviation of the samples is 0.58.

SUMMARY

As stated in the Introduction to this report, the purpose of the SO_2 study was two-fold. The first purpose was to ascertain compliance or non-compliance with the National Ambient Air Quality Standards (NAAQS). The second purpose was to calibrate the Gaussian diffusion model in order to determine expected ambient SO_2 concentrations resulting from other SO_2 emission sources, namely other fossil fuel fired power plants.

In the evaluation of the first purpose, attention was devoted to the values indicated in Table 11. The 24-hour average of 365 micrograms per cubic meter was exceeded twice during the six-month study. This occurred at Site #4 in Des Moines on March 3, 1975, and Site #8 in Ames on January 19, 1975. However, the air quality standards for SO_2 were not violated since the value of 365 micrograms per cubic meter is allowed to be exceeded once per year at each site.

The ambient SO_2 data analysis for comparison with the 3-hour NAAQS of 1300 micrograms per cubic meter was not completed at this writing. However, as demonstrated by Vaughn and Stanek[14], the 24-hour standard is the more restrictive standard in nearly all cases. Therefore, the conclusion stated previously is judged to be accurate.

In fulfilling the second purpose of this study, an attempt was made to establish a relationship between the meteorological data, ambient SO_2 monitoring results, and the power plant parameters. As mentioned previously in this report, the Brigg's plume rise formula was determined to be inadequate for the conditions monitored during this study. Since a calibrated plume rise formula has not been established, the empirical data on plume rise obtained from the analysis of photographic data was utilized. The values of sigma z were also available from the photographic data and could, along with the actual plume rise, be input into the Gaussian diffusion model as measured rather than calculated values.

Using the appropriate data shown in Tables 9 and 10, the photographic data, and the formulas derived as part of this study; the Gaussian model was used to predict the ground level concentrations of SO_2 at the various monitoring sites around the power plants. The resulting predicted values were then compared with the recorded levels of SO_2. Based on this comparison, it appears that no correlation can be established between the modeled and the recorded values. Several reasons for this lack of correlation have been proposed. In reviewing the wind frequency distributions for Ames and Des Moines (Figures 19 through 22) it is noted that contrary to normal wind patterns, seldom did the wind emanate from a primarily northwestern direction. This would be one reason why the Gaussian diffusion model occasionally predicted ground-level concentrations of zero at the monitoring sites.

Another explanation for the apparent lack of correlation would be the fact that very stable conditions occurred more frequently than expected. These stable conditions correspond to reduced dispersion of the materials in the power plant plumes. Very few hours of neutral stability, and even fewer of unstable condtions, were observed. Modeling attempted under the few unstable and neutral conditions observed indicated that the monitoring sites selected were located too close to the emission sources under study to find the maximum concentration. However, this concentration, although maximum under these conditions, would be minimal. This can be illustrated by referring to Figures 4 and 5 which shows the monitors to be located closer to the power plants than preliminary diffusion modeling had recommended. Under stable conditions, the plumes would simply tend to float over the monitors and reach ground level at great distances downwind, resulting in small contributions to the distant ground-level concentrations. This phenomenon has been observed by others as well. Reference 9 contains the statement: "The stable case can be completely eliminated from further consideration, since it contributes nothing to the ground level concentrations . . ." In summary, it appears that the Gaussian diffusion model did not work well for this study because the meteorological conditions upon which it was designed did not occur as frequently as past records indicated.

To offset the lack of applicability of the Gaussian diffusion model, DEQ pursued other avenues to determine the maximum allowable sulfur content of coal in various power plants throughout the state. One of these avenues involved the modeling of the Iowa State University and Iowa Power and Light Co. power plants and comparing the predicted ground level concentrations with the NAAQS. A simple rollback technique was then applied to the quality of coal being burned during that same time period to determine the maximum percent sulfur allowed while simultaneously maintaining the NAAQS. The results not only showed poor correlation but also gave unrealistically high values of the percent sulfur allowable in certain instances.

A second method involved utilizing frequency distributions of the occurrence of various meteorological parameters such as wind speed, wind direction, and stability classifications. This method involved determining the frequency distribution of the wind speeds and stabilities for the sixteen primary wind direction sectors. The sources under study were modeled for the wind speeds and stabilities which occurred when the wind was blowing from each of the sixteen sectors. These results were multiplied by the frequency of occurrence of the meteorological conditions resulting in a time averaged ground level concentration for that sector of the selected wind direction. This process was repeated for each of the 16 sectors, allowing a determination of the maximum ground level concentration resulting from the source under study. However, as with the first method, there was poor correlation and unrealistically high values of the percent sulfur allowable in certain instances.

DEQ's Selected Method - a combined statistical/diffusion modeling approach

Since no further progress could be made with the point estimates obtained from the unmodified Gaussian diffusion model it was decided to use a statistical approach pioneered by DEQ as part of its Air Quality Maintenance Area study. Actual monitoring data is used to obtain estimates of the percent sulfur allowable in the coal burned at a power plant while still meeting and maintaining the NAAQS for SO_2. The following is a brief outline of the procedure used to compute the percent sulfur allowable at various coal burning plants in the state.

It has been shown for sulfur dioxide that the 24 hour standard is the limiting standard in Iowa[14], and therefore, if a power plant does not exceed the 24 hour standard of 365 micrograms per cubic meter more than once a year, then we can be assured that that power plant will meet the primary and secondary ambient SO_2 standards.

We further assume that one of the eight SO_2 monitors did monitor the maximum concentrations arising from the operation of the power plant. However, since the period of study was only three months in length we need to extrapolate the 3 month geometric mean and standard geometric deviation (SGD) to a 12 month geometric mean and SGD. This can be done by analyzing the 24 hour SO2 values recorded in 1974 at seven selected sites in Iowa and obtaining the ratio of annual geometric means to maximum 3 month geometric means and the ratio of annual SGDs to maximum 3 month SGDs.

Knowing the annual geometric mean and the standard geometric deviation, we can use standard statistical techniques to determine the percent reduction necessary to meet NAAQS. Obviously, the magnitude of the reduction will depend upon two things. One, the sampling frequency and two, the number of years we want to meet NAAQS within a certain time horizon. Being a statistical technique, the method assumes that the 24 hour SO_2 readings are independent random variables and are lognormally distributed. The independence assumption has been verified by DEQ by an analysis of the SO_2 data recorded at several monitoring sites in the State while the lognormality assumption has been verified by other experimenters[15].

The statistical method also assumes that the annual SGD remains more or less constant over the years. This appears to be a reasonable assumption in view of the fact that the annual SGD is a function of the meteorology in the area, which remains more or less constant over the years.

The next step in the method is to fix the values of N (the expected number of samples per year) and P (the probability of meeting the NAAQS). Since large power plants burn large amounts of coal and affect great numbers of people, more restrictive criteria are necessary. Therefore, the following conservative values were chosen for N and P:

Large Power Plants: $N = 365, P = .999$

Medium Power Plants: $N = 61, P=.95$

In the larger metropolitan areas, continuous SO_2 samplers are used to measure ambient concentrations of SO_2 around the larger power plants, thus samples are taken every day making N equal to 365. Around smaller plants (located in primarily rural areas) SO_2 bubblers are used with a sampling frequency of once every six days, thus N equals 61.

Once the values of N and P are fixed, we can calculate the annual geometric mean that is required at a particular site in order to meet the 24-hour NAAQS. From this, the percent reduction necessary to meet NAAQS can be obtained which in turn gives the percent sulfur allowable in the coal. For ISU, the percent sulfur allowable comes out to be 3.26 while the percent sulfur allowable for Iowa Power comes out to be 3.66.

In order to extrapolate these results to the other power plants, we must make certain assumptions. First, we must assume that all other coal burning plants in the State have meteorology, terrain and operational characteristics similar to either the ISU plant or the Des Moines power plant. Secondly, although the Gaussian model does not give accurate point estimates of maximum ground level concentrations, the adjustment to these point estimates can be assumed to remain the same for similarly sized plants. Therefore, we obtain a factor which we shall call the "S factor", such that this S factor when multiplied by the point estimate obtained by using the Gaussian model will give us the correct value of the percent sulfur allowable at each power plant in Iowa.

For ISU, the Gaussian model gives a point estimate of 2.25 while the statisical method gives a point estimate of 3.26. The S factor for medium power plants, therefore, is 1.45. This S factor is then used to multiply the percent sulfur allowable computed by the Gaussian model in order to get the correct value of the percent sulfur allowable for other medium sized plants. For example, the percent sulfur allowable computed by the Gaussian model for Ames Municipal is 1.99. The correct value, then, of the percent sulfur allowable is equal to (S factor) X (Gaussian percent sulfur)

= 1.45 X (1.99) = 2.89 percent sulfur.

Similarly, for the Des Moines power plant, the Gaussian model gives a point estimate of 0.6 while the statistical method gives a point estimate of 3.66. The S factor for large power plants is therefore 6.1. This S factor is then used to multiply the percent sulfur allowable computed by the Gaussian model in order to get the correct value of the percent sulfur allowable for large power plants. For example, the percent sulfur allowable computed by the Gaussian model for Iowa Public Service's Port Neal Station is 0.87. The correct value, then, of the percent sulfur allowable is equal to (S factor) X (Gaussian percent sulfur)

= (6.1) X (0.87) = 5.31 percent sulfur.

In our analysis so far, we have considered each coal burning facility in isolation; that is, we have assumed that there is no other significant contributor to the ground level SO_2 concentrations anywhere near the facility in question. This is true in most cases except in four Iowa cities. These cities are: Clinton, Dubuque, Muscatine, and Waterloo. In the case of these cities where a coal burning installation is affected by the proximity of other large SO_2 emitters, a different method was used to arrive at the allowable percent sulfur. To illustrate, let us consider the case of Waterloo. Using the multiple source diffusion model, PTMTP, the maximum 24-hour ground level concentration arising from John Deere and Iowa Public Service's Maynard station is 3072 micrograms per cubic meter of which John Deere's contribution is 2908 ug/m^3 and Iowa Public Service's contribution is 164 ug/m^3. The percent sulfur used by John Deere in the modeling was 1.4 while the percent sulfur used by Iowa Public Service was 2.96, both based on 1974 reported data.

Taking the S factor for medium power plants into consideration, the following equation can be derived.

$$\frac{(\%\ \text{sulfur})\text{x}(244.51)}{1.4} + \frac{(\%\ \text{sulfur})\text{x}(748.5)}{2.96} = 1.45\ (365) = 529.25$$

Therefore 1.24 is then the percent sulfur allowable for John Deere, Waterloo and Iowa Public Service's Maynard Station.

Tables 12 and 13 summarize the results obtained by using DEQ's selected method.

CONCLUSION

In order to arrive at meaningful conclusions concerning Iowa coal usage, various situations were postulated and their ramifications explored. Iowa coal was assumed to have a sulfur content of 6%. In order to maximize Iowa coal usage, the relative amounts of Iowa coal mixed with 3% sulfur Illinois coal or 0.5% sulfur Wyoming coal were calculated. The amounts of Iowa coal allowable were then determined based on current coal usage at each installation and also based on total fuel requirements. In order to explore future possibilities, the success of the Iowa Coal Research Project, being conducted by Iowa State University, in reducing the sulfur content of Iowa coal to 3.5% was also assumed and the above described analysis duplicated.

Each coal burning installation was analyzed on the merits of its actual situation. Included for consideration was the present air quality at the location of the plant and the factors which have a direct influence on that air quality. These factors include the height of smokestacks, the amounts of fuel required, velocity and temperature of gases in the stacks, influence of neighboring air pollution sources, local meteorology, and other items.

Current air pollution control regulations on sulfur dioxide for existing installations limit SO_2 emissions to 6 pounds per million BTU of heat input. This limitation is uniformly applied to all coal burning facilities in Iowa. The results of the research study indicate that when a case-by-case analysis is done, the allowable SO_2 emission rate for various installations ranges from 3.02 pounds to greater than 12 pounds per million BTU heat input. This means that at a few locations in the state, a regulation more restrictive than the one which presently applies may be warranted, but a less restrictive regulation could be applicable in the majority of cases.

Tables 12 and 13 list the coal burning plants with the appropriate results. As a summary, the following results apply to the state as a whole:

Amount of Iowa Coal Allowable In Tons Per Year	Based On
1,396,190	6% S* Iowa coal mixed with 3% S Illinois coal at the present rate of coal consumption.
2,281,036	6% S Iowa coal mixed with 3% S Illinois coal at present heat requirements.
3,070,435	6% S Iowa coal mixed with 0.5% S Wyoming coal at the present rate of coal consumption.
3,738,740	3.5% S Iowa coal mixed with 3% S Illinois coal at the present rate of coal consumption.
5,025,954	6% S Iowa coal mixed with 0.5% S Wyoming coal at present heat requirement.
4,809,343	3.5% S Iowa coal mixed with 0.5% Wyoming coal at the present rate of coal consumption.
5,951,282	3.5% S Iowa coal mixed with 3% S Illinois coal at present heat requirement.
7,754,698	3.5% S Iowa coal mixed with 0.5% S Wyoming coal at present heat requirement.

*S = Sulfur

In 1974, Iowa utilized about 600,000 tons of its native coal. The results indicate, therefore, that Iowa could utilize between 230% and 1200% of current Iowa coal consumption and still be consistent with meeting health-related air pollution standards. The situation appears to be optimistic especially if the Iowa Coal Research Project is successful. It should be noted that if this is the case, beneficiated Iowa coal could be substituted for the Illinois coal used to typify a three percent sulfur coal. Even if the coal mining project fails, an increase of nearly 700% in Iowa coal consumption could be allowed.

In four Iowa cities, the proximity of large coal users compounds the air pollution situation so that the allowable pounds of SO_2 emitted is significantly less than would otherwise be possible. These cities are Clinton, Dubuque, Muscatine, and Waterloo. The SO_2 emission rate allowable listed in Tables 12 and 13 for all plants affected by the proximity of other sulfur dioxide sources in each of these four cities is identical to provide equitable application of enforcement. However, if for any reason one firm was able to utilize a lower sulfur fuel than that suggested, it would be possible to apply a less restrictive regulation to the other affected plants in the same city.

Although the results of the study contained herein indicate due optimism, it is important to also surface some appropriate cautions.

(1) These results apply to existing plants, which only have an average maximum lifetime of about 25 years. Any new large power plants would have to meet the currently effective state and federal standards which are much more restrictive for new power plants. This measure will help insure that growth will not be the cause for exceeding health-related standards in the future.

(2) Some installations may not have equipment which could burn Iowa coal because of ash or slag problems. It is not anticipated that this will be a significant obstacle to overall Iowa coal usage, however.

(3) To effectuate changes in emission standards, the Iowa Air Quality Commission will have to make amendments to DEQ departmental rules. This will involve public hearings and eventual submission to the

U.S. Environmental Protection Agency (EPA) for approval as a formal amendment to Iowa's plan for controlling air pollution. Although EPA approval is not guaranteed, DEQ feels that it has used sound engineering and statistical techniques and that it has followed the spirit and letter of applicable law passed by Congress to promote actions such as Iowa has taken.

(4) The state-of-the-art of air pollution predicting has not yet developed to the point of adequately considering topographic anomalies. Therefore, the situation in river valleys may be somewhat different than projected. However, years may elapse before this situation is fully understood.

(5) Future air monitoring may indicate the development of problems not yet foreseen, in which case a more restrictive approach would need to be taken for that specific location.

(6) Although EPA has no standards for atmospheric sulfates (sulfates are substances formed by the chemical reaction of sulfur dioxide with other materials) it has expressed concern over increased midwest emissions causing problems in New England. For this reason the largest power plants whose emissions travel farthest are proposed to be limited to 4% sulfur coal even though a less restrictive approach may have been possible. This approach should assure our eastern neighbors that we are concerned about their possible problem even if conclusive evidence is not yet available. Another reason for taking a more conservative approach with these plants is because slight errors in making projections concerning them could be significantly amplified by their great coal burning volume.

(7) The coal consumption and total heat requirement data used in this report is based on 1974 data, and may not reflect the current situation in every coal burning installation being considered.

The results of this study will be presented to the Iowa Air Quality Commission. Suggested changes in departmental rules will also be presented so that hearings can be held expeditiously. In essence, those suggestions will contain the following:

Rescind the present emission standard of 6 lb. of SO_2 per million BTU heat input for coal burning installations and replace it with an allowable emission rate of 12 pounds of SO_2 per million BTU for power plants with a coal burning heat input capacity of 500 million BTUs/hr. or less, 8 pounds of SO_2 per million BTU for power plants with a coal burning heat input capacity of 1,500 million BTUs/hr. or larger, and a specific limitation as taken from Tables 12 and 13 for all facilities in the intermediate range. Exceptions may be made for the installations in Clinton, Dubuque, Muscatine, and Waterloo. For these installations, the limitations recommended for public hearing will be those listed in Tables 12 and 13 - however, conferences held in the interim may make the limitations on some of those plants less restrictive before final actions are taken.

Table 12

6% S Iowa Coal
3% S Ill. Coal
0.5% S Wyoming Coal

Power Plant	%s Allowable	#SO_2/MMBTU Allowable	% Ia. % Wyo. Coal Allowable	%Ia./% Ill. Coal Allowable	Total Amount of Coal Consumed (TPY)	Coal Equivalent of Total BTU Consumed (TPY)	With Wyo. Mixture Amounts of Iowa Coal Allowed (TPY) Based On		With Ill. Mixture Amounts of Iowa Coal Allowed (TPY) Based On	
							Coal Consumed	Total BTUs Required	Coal Consumed	Total BTUs Required
Ames Municipal	2.89	5.78	43.5/56.2	0/0	45,359	126,455	19,731	55,008	0	0
Cedar Falls Utilities	5.55	11.10	91.8/8.2	85.0/15.0	50,037	110,743	45,934	101,662	42,531	94,132
Celotex, Dubuque	1.85	3.70	24.6/75.6	0/0	5,200	14,450	1,276	3,547	0	0
Clinton Corn	2.22	4.44	31.3/68.7	0/0	245,300	245,300	76,712	76,712	0	0
Corn Belt Power - Humbolt	4.61	9.22	74.7/25.3	53.7/46.3	44,999	336,429	33,627	251,404	24,149	180,550
Corn Belt Power - Spencer	6.0	12.0	100/0	100/0	44,870	110,380	44,870	110,380	44,870	110,380
DuPont - Clinton	2.22	4.44	31.3/68.7	0/0	114,007	114,427	35,653	35,784	0	0
Eastern Iowa - Montpelier	3.87	7.74	61.3/38.7	29.0/71.0	74,500	142,631	45,669	87,433	21,605	41,363
Grain Processing	1.51	3.02	18.4/81.6	0/0	5,290	218,840	971	40,187	0	0
Hubinger - Keokuk	4.03	8.06	64.2/35.8	34.3/65.7	65,756	65,756	42,203	42,203	22,576	22,576
Interstate Power - Dubuque	1.85	3.70	24.6/75.6	0/0	124,605	264,400	30,585	64,898	0	0
Interstate Power - Lansing Sta.	3.55	7.10	55.5/44.5	18.3/81.7	143,906	161,526	79,868	89,647	26,335	29,559
Iowa Army Ammunition	6.0	12.0	100/0	100/0	24,375	24,669	24,375	24,669	24,375	24,669
Iowa Electric - Boone	3.71	7.42	58.4/41.6	23.7/76.3	16,282	90,500	9,509	52,852	3,859	21,449
Iowa Electric - Iowa Falls	6.0	12.0	100/0	100/0	2,458	18,648	2,458	18,648	2,458	18,648
Iowa Power - Council Bluffs	3.06	6.12	46.5/53.5	2.0/98.0	281,646	443,880	130,965	206,400	5,633	0
IPS - Carroll Station	6.0	12.0	100/0	100/0	2,361	10,995	2,361	10,995	2,361	10,995

n=61, p=0.95

Table 12(cont.)

6% S Iowa Coal
3% S Ill. Coal
0.5% S Wyoming Coal

Power Plant	%s Allowable	$\#SO_2$/MMBTU Allowable	% Ia. % Wyo. Coal Allowable	%Ia./% Ill. Coal Allowable	Total Amount of Coal Consumed (TPY)	Coal Equivalent of Total BTU Consumed (TPY)	With Wyo. Mixture Amounts of Iowa Coal Allowed (TPY) Based On		With Ill. Mixture Amounts of Iowa Coal Allowed (TPY) Based On	
							Coal Consumed	Total BTUs Required	Coal Consumed	Total BTUs Required
IPS - Eagle Grove	6.0	12.0	100/0	100/0	947	8,176	947	8,176	947	8,176
IPS - Maynard	1.24	2.48	13.5/86.5	0/0	66,730	226,800	8,978	30,515	0	0
IPS - Storm Lake	6.0	12.0	100/0	100/0	3,080	21,589	3,080	21,589	3,080	21,589
Iowa Southern - Bridgeport Sta.	2.80	5.60	41.8/58.2	0/0	146,484	147,600	61,230	61,697	0	0
I.S.U. - Ames	3.26	6.52	50.2/49.8	8.7/91.3	95,293	95,293	47,837	47,837	8,290	8,290
John Deere - Dubuque	5.96	11.92	99.3/0.7	98.7/1.3	35,208	116,408	34,952	115,561	34,739	114,856
John Deere - Ottumwa	6.0	12.0	100/0	100/0	5,746	5,746	5,746	5,746	5,746	5,746
John Deere - Waterloo	1.24	2.48	13.5/86.5	0/0	48,218	48,218	6,488	6,488	0	0
Kelsey - Hayes	6.0	12.0	100/0	100/0	5,600	5,600	5,600	5,600	5,600	5,600
Mount Pleasant Utilities	6.0	12.0	100/0	100/0	2,742	2,742	2,742	2,742	2,742	2,742
Muscatine Municipal	1.51	3.02	18.4/81.6	0/0	204,949	253,157	37,636	46,489	0	0
Oscar Mayer - Davenport	6.0	12.0	100/0	100/0	31,392	66,127	31,392	66,127	31,392	66,127
Pella Municipal	5.19	10.38	85.3/14.7	73.0/27.0	75,337	75,585	64,262	64,474	54,996	55,177
Ralston Purina - Davenport	6.0	12.0	100/0	100/0	10,519	10,519	10,519	10,519	10,519	10,519
Rath Packing - Waterloo	6.0	12.0	100/0	100/0	35,547	76,947	35,547	76,947	35,547	76,947
Sibley Municipal	6.0	12.0	100/0	100/0	3,531	18,129	3,531	18,129	3,531	18,129
Spencer Municipal	6.0	12.0	100/0	100/0	500	1,500	500	1,500	500	1,500

n=61, p=0.95

Table 12(cont.)

TABLE 12 (cont.)

6% S Iowa Coal
3% S Ill. Coal
0.5% S Wyoming Coal

Power Plant	%s Allowable	#SO_2/MMBTU Allowable	% Ia. % Wyo. Coal Allowable	%Ia./% Ill. Coal Allowable	Total Amount of Coal Consumed (TPY)	Coal Equivalent of Total BTU Consumed (TPY)	With Wyo. Mixture Amounts of Iowa Coal Allowed (TPY) Based On		With Ill. Mixture Amounts of Iowa Coal Allowed (TPY) Based On	
							Coal Consumed	Total BTUs Required	Coal Consumed	Total BTUs Required
University of Iowa	6.0	12.0	100/0	100/0	41,874	52,074	41,874	52,074	41,874	52,074
Webster City Municipal	6.0	12.0	100/0	100/0	5,841	6,391	5,841	6,391	5,841	6,391
Wilson Company - Cedar Rapids	5.06	10.12	82.9/17.1	68.7/31.3	31,700	40,950	26,282	33,951	21,767	28,119
Interstate Power - Kapp Sta.	2.22	4.44	31.3/68.7	0/0	475,664	541,000	148,753	169,185	0	0
IA. Electric - Prairie C. Sta.	4.0	8.0	64.0/36.0	33.3/66.7	369,090	489,000	236,218	313,280	122,907	163,004
IA. Electric - 6th St. Sta.	4.0	8.0	64.0/36.0	33.3/66.7	150,605	197,500	96,387	126,400	50,151	65,768
IA. Electric - Sutherland Sta.	4.0	8.0	64.0/36.0	33.3/66.7	170,451	570,400	109,089	365,056	56,760	189,943
Iowa-Illinois - Riverside Sta.	4.0	8.0	64.0/36.0	33.3/66.7	411,473	752,400	263,343	481,536	137,021	250,549
Iowa Power - Des Moines	3.66	7.32	57.0/43.0	22.0/78.0	378,641	831,600	215,825	474,012	83,301	182,952
IPS - Port Neal Station	4.0	8.0	64.0/36.0	33.3/66.7	1,007,404	1,321,600	644,739	845,824	335,466	440,093
Iowa Southern - Burlington	4.0	8.0	64.0/36.0	33.3/66.7	459,890	462,000	294,330	295,680	153,143	153,846

n=365, p=0.99

				TOTALS	5,565,407	8,945,080	3,070,435	5,025,954	1,426,612	2,482,458
				PERCENT OF TOTAL COAL CONSUMED OR OF TOTAL HEAT REQUIRED			55.2%	56.2%	25.6%	27.8%

Table 13

3.5% S Iowa Coal
3% S Ill. Coal
0.5% S Wyoming Coal

Power Plant	%s Allowable	#SO_2/MMBTU Allowable	% Ia. % Wyo. Coal Allowable	%Ia./% Ill. Coal Allowable	Total Amount of Coal Consumed (TPY)	Coal Equivalent of Total BTU Consumed (TPY)	With Wyo. Mixture Amounts of Iowa Coal Allowed (TPY) Based On		With Ill. Mixture Amounts of Iowa Coal Allowed (TPY) Based On	
							Coal Consumed	Total BTUs Required	Coal Consumed	Total BTUs Required
Ames Municipal	2.89	5.78	79.7/20.3	0/0	45,359	126,455	36,151	100,785	0	0
Cedar Falls Utilities	5.55	11.10	100/0	100/0	50,037	110,743	50,037	110,743	50,037	110,743
Celotex - Dubuque	1.85	3.70	45.0/55.0	0/0	5,200	14,450	2,340	6,503	0	0
Clinton Corn	2.22	4.44	57.3/42.7	0/0	245,300	245,300	140,639	140,639	0	0
Corn Belt Power - Humbolt	4.61	9.22	100/0	100/0	44,999	336,429	44,999	336,429	44,999	336,429
Corn Belt Power - Spencer	6.0	12.0	100/0	100/0	44,870	110,380	44,870	110,380	44,870	110,380
DuPont, Clinton	2.22	4.44	57.3/42.7	0/0	114,007	114,427	65,364	65,605	0	0
Eastern Iowa - Montpelier	3.87	7.74	100/0	100/0	74,500	142,631	74,500	142,631	74,500	142,631
Grain Processing	1.51	3.02	33.7/66.3	0/0	5,290	218,840	1,781	73,676	0	0
Hubinger - Keokuk	4.03	8.06	100/0	100/0	65,756	65,756	65,756	65,756	65,756	65,756
Interstate Power - Dubuque	1.85	3.70	45.0/55.0	0/0	124,605	264,400	56,072	118,980	0	0
Interstate Power - Lansing Sta.	3.55	7.10	100/0	100/0	143,906	161,526	143,906	161,526	143,906	161,526
Iowa Army Ammunition	6.0	12.0	100/0	100/0	24,375	24,669	24,375	24,669	24,375	24,669
Iowa Electric - Boone	3.71	7.42	100/0	100/0	16,282	90,500	16,282	90,500	16,282	90,500
Iowa Electric - Iowa Falls	6.0	12.0	100/0	100/0	2,458	18,648	2,458	18,648	2,458	18,648
Iowa Power - Council Bluffs	3.06	6.12	85.3/14.7	12.0/88.0	281,646	443,880	240,244	378,630	33,798	53,270
IPS - Carroll Station	6.0	12.0	100/0	100/0	2,361	10,995	2,361	10,995	2,361	10,995

n=61, p=0.95

Table 13(cont.)

3.5% S Iowa Coal
3% S Ill. Coal
0.5% S Wyoming Coal

TABLE 13(cont.)

Power Plant	%S Allowable	#SO_2/MMBTU Allowable	% Ia. % Wyo. Coal Allowable	%Ia./% Ill. Coal Allowable	Total Amount of Coal Consumed (TPY)	Coal Equivalent of Total BTU Consumed (TPY)	With Wyo. Mixture Amounts of Iowa Coal Allowed (TPY) Based On		With Ill. Mixture Amounts of Iowa Coal Allowed (TPY) Based On	
							Coal Consumed	Total BTUs Required	Coal Consumed	Total BTUs Required
IPS - Eagle Grove	6.0	12.0	100/0	100/0	947	8,176	947	8,176	947	8,176
IPS - Maynard	1.24	2.48	24.7/75.3	0/0	66,730	226,800	16,460	55,944	0	0
IPS - Storm Lake	6.0	12.0	100/0	100/0	3,080	21,589	3,080	21,589	3,080	21,589
Iowa Southern - Bridgeport Sta.	2.80	5.60	76.7/23.3	0/0	146,484	147,600	112,353	113,209	0	0
I.S.U. - Ames	3.26	6.52	92.0/8.0	52.0/48.0	95,293	95,293	87,670	87,670	49,552	49,552
John Deere - Dubuque	5.96	11.92	100/0	100/0	35,208	116,408	35,208	116,408	35,208	116,408
John Deere - Ottumwa	6.0	12.0	100/0	100/0	5,746	5,746	5,746	5,746	5,746	5,746
John Deere - Waterloo	1.24	2.48	24.7/75.3	0/0	48,218	48,218	11,894	11,894	0	0
Kelsey - Hayes	6.0	12.0	100/0	100/0	5,600	5,600	5,600	5,600	5,600	5,600
Mount Pleasant Utilities	6.0	12.0	100/0	100/0	2,742	2,742	2,742	2,742	2,742	2,742
Muscatine Municipal	1.51	3.02	33.7/66.3	0/0	204,949	253,157	68,999	85,230	0	0
Oscar Mayer - Davenport	6.0	12.0	100/0	100/0	31,392	66,127	31,392	66,127	31,392	66,127
Pella Municipal	5.19	10.38	100/0	100/0	75,337	75,585	75,337	75,585	75,337	75,585
Ralston Purina - Davenport	6.0	12.0	100/0	100/0	10,519	10,519	10,519	10,519	10,519	10,519
Rath Packing - Waterloo	6.0	12.0	100/0	100/0	35,547	76,947	25,547	76,947	35,547	76,947
Sibley Municipal	6.0	12.0	100/0	100/0	3,531	18,129	3,531	18,129	3,531	18,129
Spencer Municipal	6.0	12.0	100/0	100/0	500	1,500	500	1,500	500	1,500

n=61,p=0.95

Table 13(cont.)

3.5% S Iowa Coal
3% S Ill. Coal
0.5% S Wyoming Coal

Power Plant	%s Allowable	#SO_2/MMBTU Allowable	% Ia. % Wyo. Coal Allowable	%Ia./% Ill. Coal Allowable	Total Amount of Coal Consumed (TPY)	Coal Equivalent of Total BTU Consumed (TPY)	With Wyo. Mixture Amounts of Iowa Coal Allowed (TPY) Based On		With Ill. Mixture Amounts of Iowa Coal Allowed (TPY) Based On	
							Coal Consumed	Total BTUs Required	Coal Consumed	Total BTUs Required
University of Iowa	6.0	12.0	100/0	100/0	41,874	52,074	41,874	52,074	41,847	52,074
Webster City Municipal	6.0	12.0	100/0	100/0	5,841	6,391	5,841	6,391	5,841	6,391
Wilson Company - Cedar Rapids	5.06	10.12	100/0	100/0	31,700	40,950	31,700	40,950	31,700	40,950
Interstate Power - Kapp Sta.	2.22	4.44	57.3/42.7	0/0	475,664	541,000	272,714	310,173	0	0
IA. Electric - Prairie C. Sta.	4.0	8.0	100/0	100/0	369,090	489,500	369,090	489,500	369,090	489,500
IA. Electric - 6th St. Sta.	4.0	8.0	100/0	100/0	150,605	197,500	150,605	197,500	150,605	197,500
IA. Electric - Sutherland Sta.	4.0	8.0	100/0	100/0	170,451	570,400	170,451	570,400	170,451	570,400
Iowa-Illinois - Riverside Sta.	4.0	8.0	100/0	100/0	411,473	752,400	411,473	752,400	411,473	752,400
Iowa Power - Des Moines	3.66	7.32	100/0	100/0	378,641	831,600	378,641	831,600	378,641	831,600
IPS - Port Neal Station	4.0	8.0	100/0	100/0	1,007,404	1,321,600	1,007,404	1,321,600	1,007,404	1,321,600
Iowa Southern - Burlington	4.0	8.0	100/0	100/0	459,890	462,000	459,890	462,000	459,890	462,000
n=365, p=0.99				TOTALS	5,565,407	8,945,080	4,809,343	7,754,698	3,789,985	6,308,582
				PERCENT OF TOTAL COAL CONSUMED OR OF TOTAL HEAT REQUIRED			86.4%	86.7%	68.1%	70.5%

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APPENDIX A

FIRST QUARTERLY PROGRESS REPORT

submitted to the

IOWA DEPARTMENT OF ENVIRONMENTAL QUALITY

on the

ASSESSMENT OF ATMOSPHERIC STABILITY CHARACTERISTICS

December 1, 1974

Eugene S. Takle

Eugene S. Takle
Principal Investigator

Robert E Post

Robert E. Post
Principal Investigator

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I. Introduction

II. Methods of determining atmospheric stability

- A. Turner model
- B. Power law profile
- C. Temperature profile
- D. Acoustic sounder
- E. Instrumented balloon
- F. Plume photographs

III. Summary and status report

I. Introduction

The general mission to characterize the atmospheric stability for the SO_2 study has been and will be approached from a number of different viewpoints. The scientific literature is replete with methods of performing such a task; however, the very abundance of diverse methods attests to the complexity of making such assessments for the myriad of atmospheric and topographical conditions encountered in actual dispersion problems. This stems from the necessity of obtaining the most competent assessment of atmospheric stability within the limitations of the personnel and economic resources available.

Section II describes techniques to be explored in this study. While we anticipate that some of these may not prove to be sufficiently sensitive for the purpose of the present SO_2 program, we feel an exploration of a wide variety of techniques may provide guidance to DEQ for future instrumentation programs. The significant contribution of instrumentation and data by the U.S. Atomic Energy Commission Ames Laboratory Research Reactor Meteorology group, and the Agronomy and Earth Science Departments of Iowa State University should be acknowledged since no contract funds were expended for purchase and installation of equipment nor gathering of data from these instruments.

II. Methods of determining atmospheric stability

A. Turner model.

The method of calculating concentrations of atmospheric contaminants proposed by Turner[1] involves a bare minimum of atmospheric variables as input parameters. While the applicability of this model is severely limited, the requisite atmospheric measruements can easily be made and, for the most part, are readily available from more extensive measurement programs.

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[1] D.B. Turner (1969): Workbook of Atmospheric Dispersion Estimates. U.S. Department of Health, Education and Welfare.

Turner parameterizes the vertical mixing due to solar heat flux by considering the solar altitude and modifying the result by any existing cloud cover. A calculation of solar altitude for time of day and day of year would then provide the initial step for using the Turner model and an informative reference point for more sophisticated approaches. This has been done for Ames by Engel and Takle[2] with the resulting graph shown in Fig. 1. The altitude of the sun above the horizon is depicted by curves labeled from 0° to 70° (with a maximum on June 20 of 71.4°). The other curves (not directly pertinent to this study) give the solar azimuth as measured from north. Turner categorizes incoming solar radiation as a function of altitude, α , as follows:

$\alpha > 60^\circ$: strong

$60^\circ > \alpha > 35^\circ$: moderate

$35^\circ > \alpha > 15^\circ$: slight.

Figure 1 together with hourly cloud cover observations and mean horizontal wind speed at 10 meters can be used to determine stability for this simple model. While the limitations of this approach are clearly recognized, the validity of the scheme can easily be determined, and if under certain conditions this method proves competent, a substantial saving in instrumentation expense may be realized by DEQ in future enforcement programs. Conversely, demonstrated incompetence would eliminate this method for use in environmental impact statements.

A significant improvement upon Turner's parameterization of surface

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[2] T.M. Engel and E.S. Takle (1974): Computation of solar altitude and azimuth. To appear in the Iowa State Journal of Research.

heat flux by α and cloud cover can be made by measuring solar radiation directly. This is being done by an analog recording of solar radiation as measured by an Epply pyrheliometer. A typical recording is shown in Fig. 2. A student is currently being employed to reduce these data to 20 minute averages. These can then be combined with nighttime hourly cloud cover observations as a first improvement upon Turner's model.

B. Power-law profile

A completely independent method of approaching a specification of atmospheric stability is the observation of the vertical variation of time averaged horizontal wind velocity. The increase in horizontal wind speed with height has long been recognized and the magnitude of this gradient variation is governed primarily by atmospheric stability. This approach is very operationally oriented and has enjoyed widespread use in a variety of applications. The so-called power-law profile is based on the premise that

$$\frac{v_2}{v_1} = \left(\frac{z_2}{z_1}\right)^{\beta}$$

where z_1 and z_2 are two different levels above the surface, v_1 and v_2 are the time averaged horizontal wind velocities at these respective heights and β is some number between 0 and 1 whose magnitude depends on atmospheric stability. Therefore, by measuring v_1 and v_2 and knowing z_1 and z_2 β, and hence stability, can be inferred. Calculations of β based on data accumulated in past years from the AEC Ames Lab Research Reactor meteorological tower instrumented at 5 levels from 2 m to 32 m have given results in good agreement with diurnal and seasonal behavior observed in other scientific studies. A sample of some preliminary

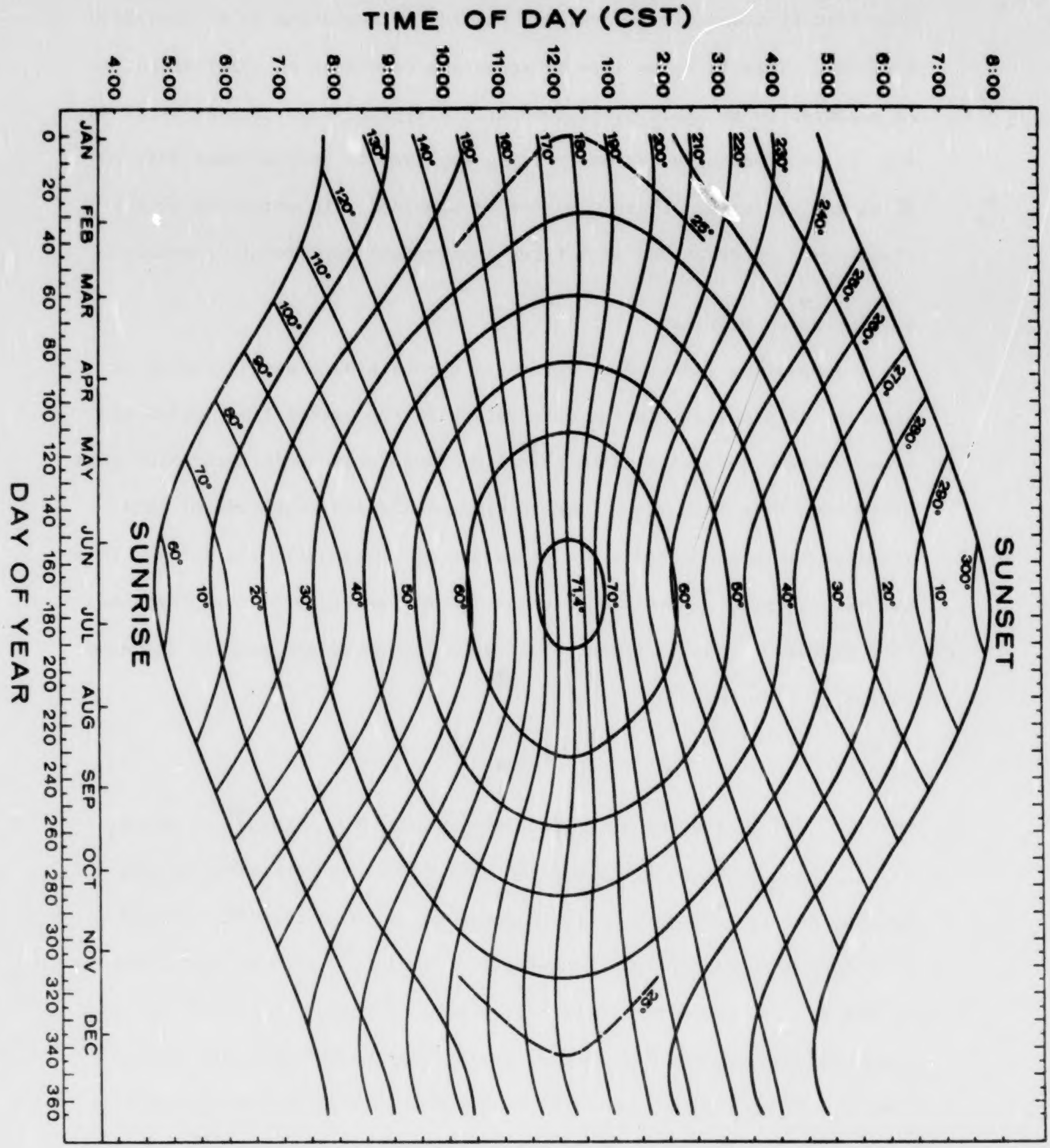

Figure 1. Solar altitude and azimuth for Ames, Iowa.

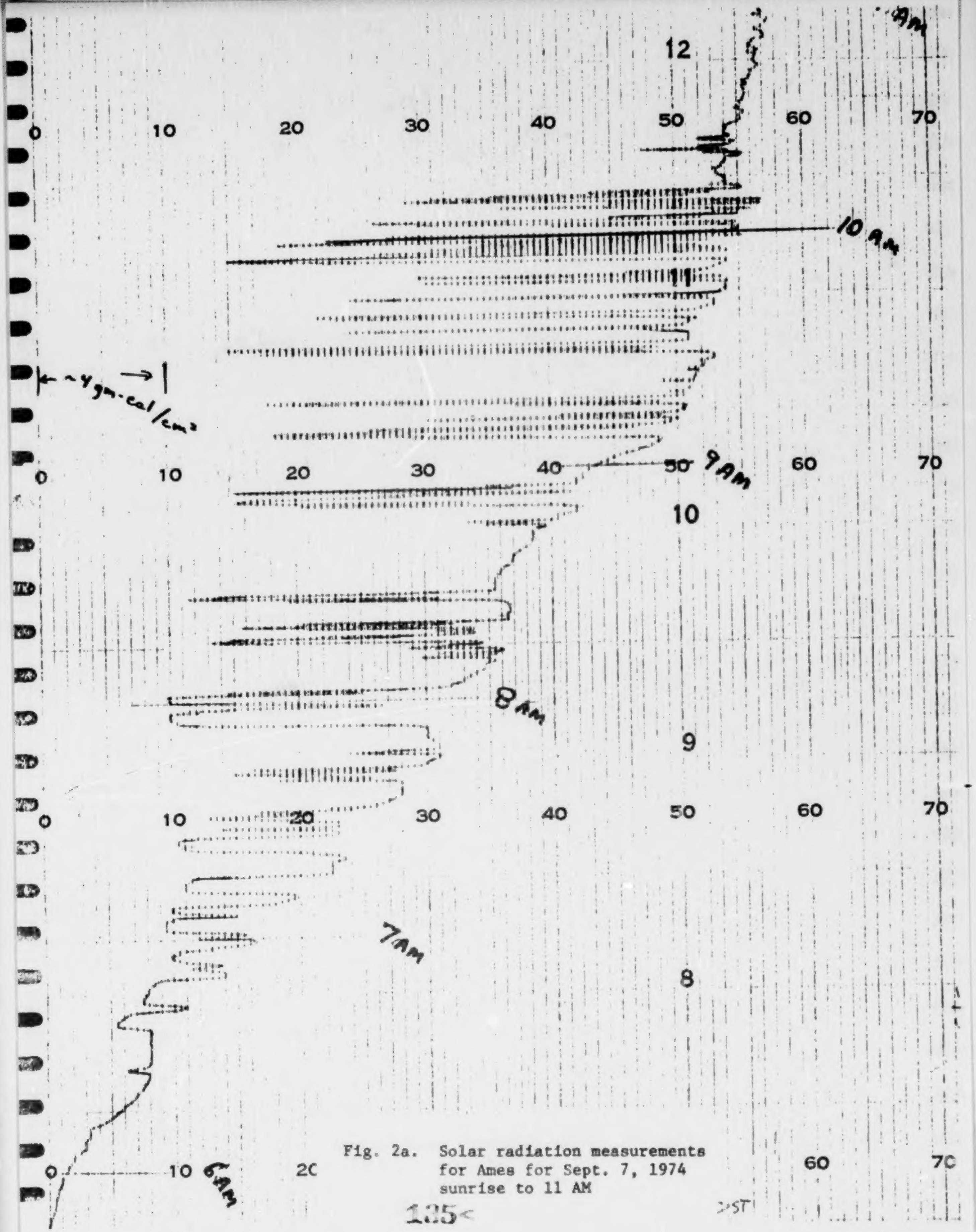

Fig. 2a. Solar radiation measurements
for Ames for Sept. 7, 1974
sunrise to 11 AM

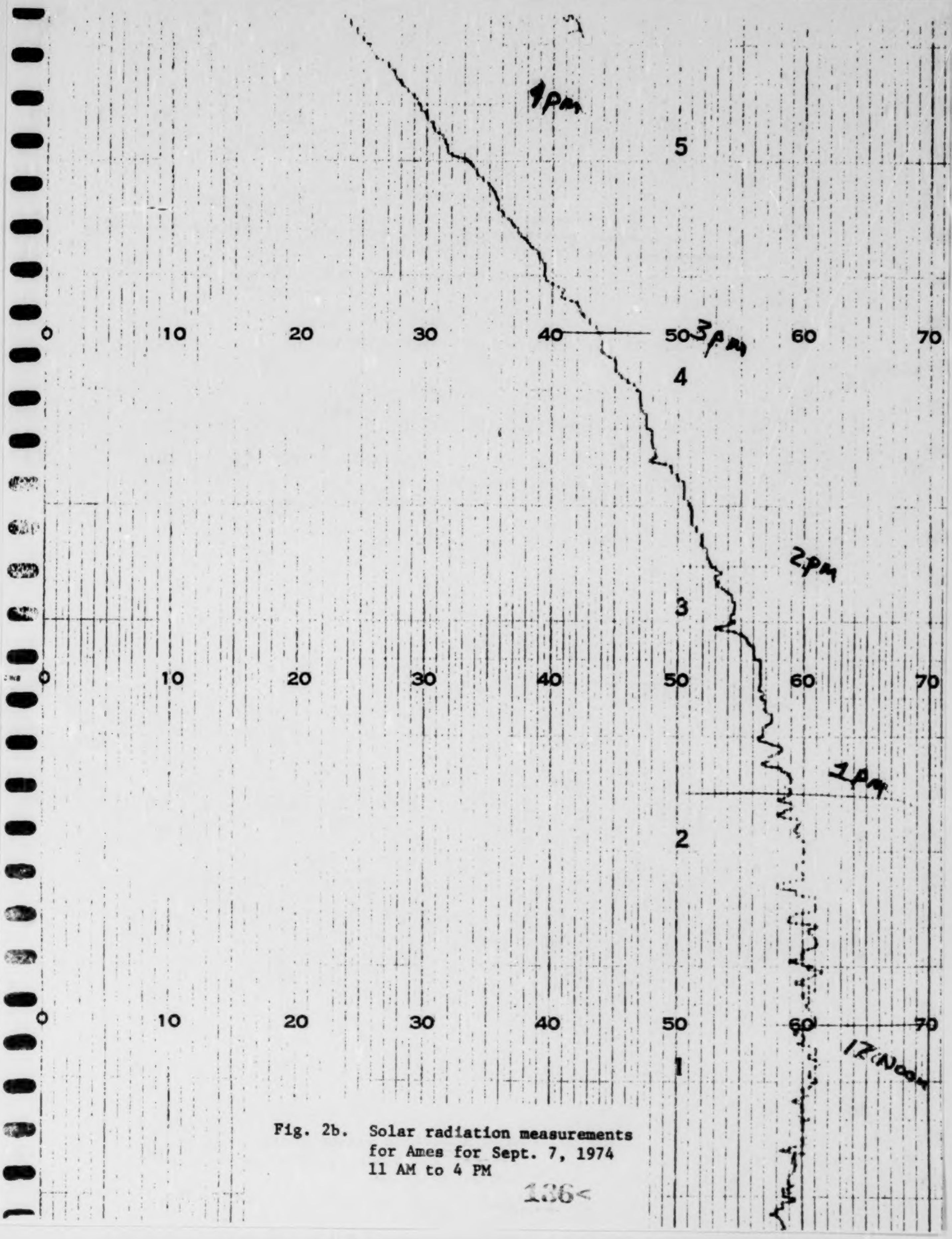

Fig. 2b. Solar radiation measurements for Ames for Sept. 7, 1974 11 AM to 4 PM

calculations[3] of β is shown in Fig. 3. This then provides a continuous variable, β , which ranges from about 0.13 (most unstable) to about 0.8 (very stable). While the magnitude of β strictly speaking, characterizes stability only within the depth of the surface layer defined by the uppermost wind speed measurement, this is after all the region of the atmosphere interrogated by the SO_2 monitors. A statement of the magnitude of atmospheric mixing in this layer then will yield information about vertical transport of pollutants within this layer. Successful balloon operation (to be discussed in II,E) should extend the maximum height of such measurements to maximum balloon altitude provided appropriate (if possible) adjustments are made to account for the "non-simultaneous" nature of such measurements.

Alternate specifications of the velocity profile utilizing logarithmic and log-linear profiles will also be explored as time permits.

C. Temperature profile

A third method of measuring stability is to consider the vertical temperature structure since this property governs thermal turbulence. Temperature is currently being measured at 4 levels up to 16 m (operation at 32 m is anticipated within the near future) at the AEC tower. This will allow for identification of the presence and strength of ground-based inversions.

D. Acoustic sounder

The acoustic sounder is an instrument which has been introduced into dispersion studies relatively recently. A transmitted acoustic pulse

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[3] E.S. Takle (1974): A special topics course on atmospheric dispersion applied to agriculturally generated pollutants. Submitted to Journal of Agronomic Education.

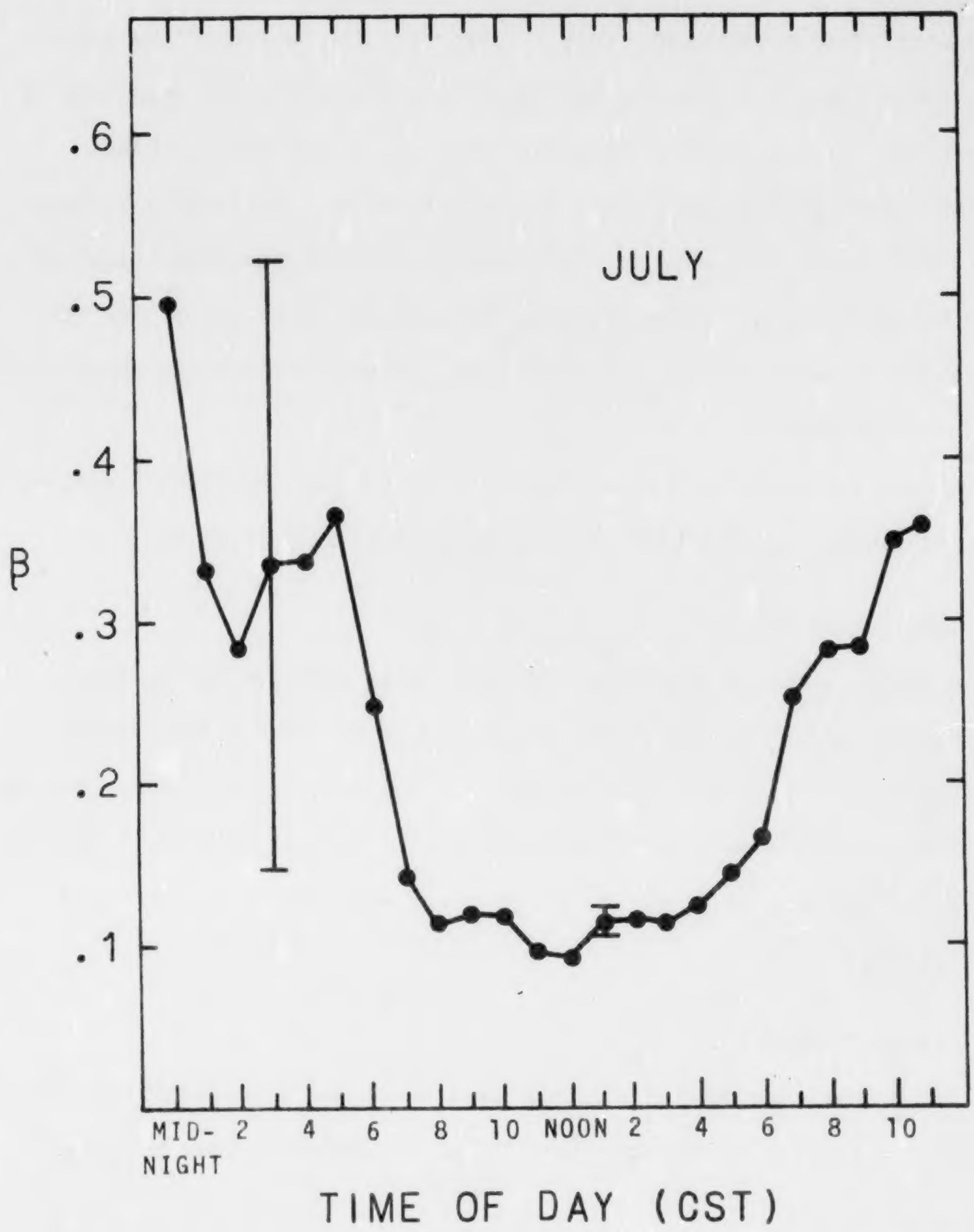

Figure 3. Diurnal variation of stability parameter β for July in Ames.

on energy is partially reflected by diabatic (non-neutral) vertical temperature structure. Visual recordings can then be scanned for temperature anomalies within the vertical range of the sounder (up to about 500 m). Valuable guidance can then by provided on the justification and procedure for extrapolating ground-based measurements through that depth of the atmosphere contaminated by the plume.

The circuitry for the acoustic echo sounder constructed at Iowa State University has been extensively tested and, where necessary, improved while we are waiting for the arrival of the facsimile recorder. At the present time, we still have plans to modify the power amplifier circuitry, which should complete the redesign process. As the modules have been modified and tested and proven satisfactory for use in the sounder, we have also prepared duplicate circuit boards. Thus, all of the circuit boards for the second sounder have been fabricated, so we should be able to put together the second sounder in a short period of time. A new recording technique[4] involving a storage oscilloscope is also being explored at this time. This technique offers some advantages in flexibility and resolution over the facsimile recorder.

E. Instrumented balloon

A non-contract endeavor which has absorbed a significant amount of time has been the design, construction and testing of a balloon system capable of making wind speed, wind direction and temperature measurements up to 500 feet. It is anticipated that this program will soon be taken over by DEQ to curtail time and expense diversion from the contract mission.

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[4] Described in the November 1974 Transactions on Geoscience Electronics.

F. Plume photographs

Photographs now becoming available from DEQ camera systems will be analyzed and compared with previously mentioned techniques for specification of atmospheric conditions as they actually affect the power plant plume. The dispersion of the plume about its centerline and the meandering of this axis will be measured. Cooperative efforts with DEQ are under way to maximize information available from the photographic system.

III. Summary

The following outline gives the status of information, gathering sources used in this study.

A. Data currently available

1. AEC Tower
    a) surface temperature (2 m)
    b) temperature difference from surface (4 m, 8 m, 16 m)
    c) time-averaged horizontal wind speed (2 m, 4 m, 8 m, 16 m, 32 m)
    d) wind direction (16 m)

2. Agronomy building, ISU - solar radiation

3. Des Moines Weather Service - hourly observations of a wide variety of meteorological variables

4. Curtiss Hall, ISU
    a) meteorological data to forecast wind conditions for determining "Go", "No-Go" status for full-scale observation program
    b) barometric pressure

B. Data to be available in near future

1. AEC Tower
    a) temperature difference from surface (32 m)
    b) wind direction (32 m) possibly

2. Balloon flights at horse pasture trailer
    a) wind speed
    b) wind direction
    c) temperature difference from surface

3. Surface measurements at horse pasture
    a) temperature
    b) humidity (possibly on hand-measured basis)

4. Coover Hall, ISU - acoustic sounder measurements

C. Other activities

Studies are in progress in cooperation with DEQ personnel on interpretation and reliability of pre-analyzed meteorological data from DEQ instrumentation.

The contract statement of expenditures on the following page itemizes contract expenses incurred through October 31, 1974. The only budget item where expenditures have exceeded allotment is "supplies" where unbudgeted balloon expenses have inflated this category. A corresponding decrease in expenses in "other" will be necessary to offset this deficit. This latter category includes $4000 for acoustic sounder construction costs, $310 for chart paper and $540 for collecting observations from Des Moines and Omaha. Some saving will be realized in this last item.

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                         CONTRACT STATEMENT  10-31-74     400-45-00
EUGENE S TAKLE           IDFQ
AGRONOMY
CURTISS HALL                   07-01-74 THRU 06-30-75

                                  BUDGETED      CURR. MO.       EXPENDED     UNEXPENDED
SALARIES & WAGES          [illegible],47[illegible].00      1,065.90       2,547.40       3,622.60
EMPLOYEE BENEFITS                   108.00          5.85          11.70          96.30
PREMIUM TIME                           .00          0.00           0.00           0.00
HONORARIA                              .00          0.00           0.00           0.00
EQUIPMENT                         2,941.00          0.00           0.00       2,941.00
SUPPLIES                            100.00         71.27         122.85          28.85-
TRAVEL                              390.00          0.00          15.15         374.85
PRINTING                              0.00          0.00           0.00           0.00
COMPUTER TIME                         0.00          0.00           0.00           0.00
STIPENDS                              0.00          0.00           0.00           0.00
TUITION                                .00          0.00           0.00           0.00
ADVANCE                                .00          0.00           0.00           0.00
OTHER                             4,855.00          0.00           0.00       4,855.00
ENCUMBRANCES                           .00          0.00       2,993.00       2,993.00-
PAYROLL ENCUMBRANCES                   .00          0.00       2,732.00       2,732.00-
 TOTAL - DIRECT COSTS            14,814.00**    1,143.02 **    8,478.10**     6,335.90 **

INDIRECT PAY-ENCUM  [illegible]%        .00          0.00            .00           0.00
INDIRECT EXPEND     [illegible]%        .00          0.00            .00           0.00
INDIRECT ENCUM      [illegible]%        .00          0.00            .00           0.00
RESTRICTED FUNDS                       .00          0.00            .00           0.00
BUDGET & EXPENSE TOTAL           14,814.00      1,143.02       8,478.10       6,335.90

           PER CENT CONSUMED          AVERAGE MONTHLY EXPENDITURES
                                    CURRENT        HIGH          LOW
                 18.5[illegible]                  682.28     1,2[illegible]3.50       341.58

              CONTRACT WILL BE CONSUMED IN  13.2 MONTHS AT CURRENT RATE.
                   8 MONTHS ARE REMAINING ON THIS CONTRACT.

                         ***** CLASS TOTALS *****
010--  1,716.00   016--      11.70   020--     831.40   035--     122.85   051--      15.15

CONTRACT TOTALS       RECEIPTS   ALLOCATIONS   EXPENDITURES   ENCUMBRANCES
                          .00           .00     2,7[illegible].1[illegible]       5,725.00

STATEMENT BALANCE    5,746.10-       CONTRACT FREE BALANCE      6,335.90
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APPENDIX B

SECOND QUARTERLY PROGRESS REPORT

submitted to the

IOWA DEPARTMENT OF ENVIRONMENTAL QUALITY

on the

ASSESSMENT OF ATMOSPHERIC STABILITY CHARACTERISTICS

1 March 1975

Eugene S. Takle

Eugene S. Takle
Principal Investigator

Robert E. Post

Robert E. Post
Principal Investigator by EST

CONTENTS

I. Introduction

II. Stability Calculations

III. Acoustic Sounder

IV. Summary

I. Introduction

Progress has been realized in several aspects of the stability assessment study during this report period. In the First Quarterly Progress Report of 1 December 1974 the theoretical aspects of the stability calculations were discussed. Discussions with DEQ personnel and "dry run" data analysis calculations have further identified the specifics of transforming the stability measurements into usable input to DEQ dispersion models. The acoustic sounder has been successfully operated at two different sites, and is providing very vivid pictures of some atmospheric motions and structure.

II. Stability calculations

A literature search is being continued to identify the various methods that have been used to extract from field measurements numerical representations of stability. In each of these investigations a stability calculation was chosen which would utilize available meteorological data. Because of the wide range of data available to this study, several methods are explored, intercompared for reliability, and studied individually for sensitivity.

The stability analysis is carried out by calculating each independent stability parameter in a separate subroutine. The main program will then read in data, call subroutines for calculating each parameter, make some decisions on data reliability, perform averaging as seems appropriate, calculate necessary dispersion model input variables (e.g., σ's) and print out results.

The following paragraphs delineate the specific calculations made in the seven primary subroutines.

Stability Parameter Analysis Program

1. PWRLAW

The power law exponent (β) is calculated using the relationship:

$$\frac{u_1}{u_2} = \left(\frac{z_1}{z_2} \right)^{\beta}$$ which can be solved for β to give

$$\beta = \frac{\ln \frac{u_1}{u_2}}{\ln \frac{z_1}{z_2}} .$$

The final value for each hour is a weighted average of all possible combinations of wind speeds and their respective levels using the weights:

1/30 for 2 m to 4m

1/12 for 2 m to 8m, 2m to 16m

1/10 for 2m to 32m, 4m to 8m, 4m to 16m

1/8 for 4m to 32m, 8m to 16m, 8m to 32m, 16m to 32m

2. PASTAB

A value for stability class is calculated in a manner similar to Pasquill's method. Inputs are 8m wind speed and cloud amounts (high, middle, and low). Subroutine SUNANG (see Fig. 1, First Quarterly Progress Report) is also used to estimate solar intensity.

The comparison of classes is as follows:

-3 = A

-2 = B

-1 = C

0 = D

+1 = E

+2 = F

3. RICHNO

Values of the gradient Richardson number are calculated in several different ways. The appropriate equation is:

$$R_i = \frac{\frac{g}{\theta}\frac{\partial\theta}{\partial z}}{\left(\frac{\partial\bar{u}}{\partial z}\right)^2} = \frac{\frac{g}{T}\left[\frac{\partial T}{\partial z} + \Gamma_d\right]}{\left(\frac{\partial\bar{u}}{\partial z}\right)^2}$$ with the assumption that

$$\frac{K_H}{K_m} = 1.$$

The derivative in the denominator is approximated in two ways: first using the 32m and 2m winds and second using the 32m winds and assuming the winds go to zero at $z = 0$. The second approximation reduces the chance of spuriously high values of R_i.

As the ventilating fan on the 32m temperature sensing element is not working, $\frac{\partial T}{\partial z}$ was approximated in two ways also. This derivative was approximated using T(32m) - T(2m) unless:

low cloud amt. < 6/10 and sun altitude > 15°

mid cloud amt. < 6/10 and sun altitude > 15°

high cloud amt. < 8/10 and sun altitude > 15°

sum low and mid < 8/10 and sun altitude > 15°

then the values of T(16m) - T(2m) is used. If this is the case, the ICODE = 1, otherwise ICODE = 0.

4. LINFIT

This subroutine estimates the roughness height (z_0) and friction velocity (u_*) which will be needed in the MONOBL subroutine. For any hour in which $-0.5 < R_i < 0.5$, the mean wind values (x_i) were linearly regressed on the natural logarithm of the height of the wind measurements (y_i). For a neutral situation this should be a straight line. The y intercept is $\ln(z_0)$ and the slope is related to u_*.

$$b_0 = \frac{\Sigma x_i^2 \ \Sigma y_i - \Sigma x_i \ \Sigma x_i y_i}{n\Sigma x_i^2 - \Sigma^2 x_i} \qquad b_0 = \text{y intercept}$$

$$b_1 = \frac{n \ \Sigma x_i y_i - \Sigma x_i \Sigma y_i}{n\Sigma x_i^2 - \Sigma^2 x_i} \qquad b_1 = \text{slope}$$

$z_0 = \exp\ (b_0)$

$u_* = k/b_1$ k = von karman's const. (set at 0.4)

Therefore, the Richardson number can be used to determine stability, and, if near neutral, the values for z_0 and u_* should be good estimates.

5. MONOBL

In this subroutine the reciprocal of the Monin-Obukhov length (1/L) is calculated for different stabilities.

From Shir and Shieh, JAM, 13, p. 190 (1974)

$$1/L = \pm \ [\ d \ \ell n \ (1.2 + 10/z_0)]^2 \ 10^{f(s)}$$

where $f(s) = -a/(1 + b|s|^c)$.

Here s is the stability class determined in PASTAB (the sign of 1/L is the sign of the stability class and s = 0 is neutral), a = 4, b = 1.3, c = 0.85, d = 0.216586, and z_0 is the roughness height determined in LINFIT.

As the program now is written, the only time the result is meaningful is when conditions are near neutral because only then is z_0 meaningful. z_0 should not change rapidly, so the next step will be to incorporate a method to store a z_0 value for use in non-neutral situations until another near neutral comes around.

1/L is also determined from R_i.

Commonly used empirical relationships (graph in Workshop on Micrometeorology, p. 79, 1972)

$$1/L = \frac{R_i}{z(1 - \beta R_i)} \quad \text{for stable} \quad (0.14 > R_i > 0.01)$$

$$1/L = 0 \quad \text{for neutral} \quad (0.01 > R_i > -0.01)$$

$$1/L = \frac{R_i}{z} \quad \text{for unstable} \quad (R_i < -0.01)$$

where here β is the coefficient of the linear term in the log-linear law.

$$u = \frac{u_*}{k} \left(\ell n \frac{z}{z_0} + \beta \frac{z}{L} \right)$$

I used β = 7, although sensitivity tests will be run with β as low as 4.7 (Workshop on Micrometeorology, p. 31)

6. EDDYDI

Will be used to calculate eddy diffusivities (K). So far this is just a dummy subroutine that assigns K = 0.

7. TEMPGR

In this subroutine the potential temperature gradient is calculated in two ways:

$$\frac{\partial \theta}{\partial z} = \frac{T(32) - T(2)}{30} + \Gamma_d$$

and

$$\frac{\partial \theta}{\partial z} = \frac{T(16) - T(2)}{14} + \Gamma_d$$

This was done because of the problem with the 32m temperature sensor (non-ventilated). During periods when radiation is negligible the 32m temperature is used; otherwise the 16m value is taken.

The following two pages show the computer output for the stability analysis carried out for 1 December 1974.

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          STABILITY PARAMETER ANALYSIS FOR MONTH 12 OF 1974


                         CALCULATED VALUES FOR DAY  1

HR    RI   #1      1/L  32M        64M          96M         128M          Z0            U*
 0  -0.159E-02   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.467E-01   0.354E 00
 1  -0.103E-02   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.750E-01   0.409E 00
 2  -0.142E-02   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.546E-01   0.342E 00
 3  -0.352E-02   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.190E-02   0.216E 00
 4  -0.550E-02   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.343E-02   0.175E 00
 5   0.524E-01   0.256E-02   0.129E-02   0.861E-03   0.646E-03   0.111E 01   0.111E 02
 6   0.367E-01   0.690E-02   0.345E-02   0.230E-02   0.173E-02   0.111E 01   0.111E 02
 7  -0.554E-02   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.213E-03   0.158E 00
 8   0.128E 00   0.388E-01   0.194E-01   0.129E-01   0.970E-02   0.111E 01   0.111E 02
 9   0.347E 00   0.111E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 01   0.111E 02
10   0.496E 00   0.111E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 01   0.111E 02
11   0.150E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 01   0.111E 02
12   0.150E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 01   0.111E 02
13   0.160E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 01   0.111E 02
14   0.100E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 01   0.111E 02
15   0.237E 01   0.111E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 01   0.111E 02
16   0.308E 01   0.111E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 01   0.111E 02
17  -0.170E-01  -0.531E-03  -0.265E-03  -0.177E-03  -0.133E-03   0.666E-07   0.381E-01
18  -0.825E-02   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.481E-04   0.151E 00
19   0.451E-01   0.206E-02   0.103E-02   0.686E-03   0.515E-03   0.314E-01   0.253E 00
20   0.556E-01   0.245E-02   0.122E-02   0.817E-03   0.612E-03   0.111E 01   0.111E 02
21   0.148E 00   0.111E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 01   0.111E 02
22   0.665E-01   0.389E-02   0.194E-02   0.130E-02   0.971E-03   0.111E 01   0.111E 02
23   0.960E-01   0.975E-02   0.488E-02   0.325E-02   0.244E-02   0.111E 01   0.111E 02

HR    RI   #2      1/L  32M        64M          96M         128M          Z0            U*
 0  -0.206E-03   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.467E-01   0.354E 00
 1  -0.179E-03   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.750E-01   0.409E 00
 2  -0.251E-03   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.546E-01   0.342E 00
 3  -0.263E-03   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.190E-02   0.216E 00
 4  -0.441E-03   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.343E-02   0.175E 00
 5   0.559E-02   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.104E-01   0.222E 00
 6   0.600E-02   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.137E-02   0.171E 00
 7  -0.324E-03   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.213E-03   0.158E 00
 8   0.522E-02   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.653E-05   0.124E 00
 9   0.151E-01   0.529E-03   0.265E-03   0.176E-03   0.132E-03   0.345E-04   0.166E 00
10   0.231E-01   0.114E-02   0.572E-03   0.381E-03   0.286E-03   0.271E-03   0.213E 00
11   0.246E 00   0.111E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 01   0.111E 02
12   0.359E 00   0.111E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 01   0.111E 02
13   0.306E 00   0.111E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 01   0.111E 02
14   0.276E 00   0.111E 02   0.111E 02   0.111E 02   0.111E 02   0.111E 01   0.111E 02
15   0.868E-01   0.692E-02   0.346E-02   0.231E-02   0.173E-02   0.111E 01   0.111E 02
16   0.672E-01   0.396E-02   0.198E-02   0.132E-02   0.991E-03   0.111E 01   0.111E 02
17  -0.364E-03   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.666E-07   0.381E-01
18  -0.392E-03   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.481E-04   0.151E 00
19   0.662E-02   0.000E 00   0.000E 00   0.000E 00   0.000E 00   0.304E-01   0.253E 00
20   0.157E-01   0.551E-03   0.276E-03   0.184E-03   0.138E-03   0.377E 00   0.336E 00
21   0.151E-01   0.527E-03   0.263E-03   0.176E-03   0.132E-03   0.712E-02   0.166E 00
22   0.253E-01   0.962E-03   0.481E-03   0.321E-03   0.240E-03   0.576E 00   0.354E 00
23   0.353E-01   0.147E-02   0.735E-03   0.490E-03   0.368E-03   0.559E 00   0.300E 00
```

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    Z          U*                       TGRAD1      TGRAD2          R       ICODE
0.467E-01  0.354E 00                 0.270E-02  -0.260E-03   0.000E 00    0
0.750E-01  0.409E 00                 0.980E-02  -0.260E-03   0.000E 00    0
0.546E-01  0.342E 00                 0.270E-02  -0.260E-03   0.000E 00    0
0.196E-02  0.216E 00                 0.980E-02  -0.260E-03   0.000E 00    0
0.543E-02  0.175E 00                 0.980E-02  -0.260E-03   0.000E 00    0
0.111E 01  0.111E 02                 0.241E-01   0.313E-02   0.000E 00    0
0.111E 01  0.111E 02                 0.980E-02   0.313E-02   0.000E 00    0
0.213E-03  0.158E 00                 0.590E-02  -0.260E-03   0.000E 00    0
0.111E 01  0.111E 02                 0.900E-02   0.313E-02   0.000E 00    0
0.111E 01  0.111E 02                 0.590E-01   0.105E-01   0.000E 00    0
0.111E 01  0.111E 02                 0.103E 00   0.295E-01   0.000E 00    0
0.111E 01  0.111E 02                 0.210E 00   0.605E-01   0.000E 00    1
0.111E 01  0.111E 02                 0.267E 00   0.651E-01   0.000E 00    1
0.111E 01  0.111E 02                 0.240E 00   0.765E-01   0.000E 00    1
0.111E 01  0.111E 02                 0.190E 00   0.551E-01   0.000E 00    1
0.111E 01  0.111E 02                 0.140E 00   0.451E-01   0.000E 00    0
0.111E 01  0.111E 02                 0.384E-01   0.305E-01   0.000E 00    0
0.660E-07  0.361E-01                 0.169E-01  -0.260E-03   0.000E 00    0
0.461E-04  0.131E 00                 0.260E-02  -0.260E-03   0.000E 00    0
0.304E-01  0.255E 00                 0.270E-02   0.313E-02   0.000E 00    0
0.111E 01  0.111E 02                 0.200E-02   0.647E-02   0.000E 00    0
0.111E 01  0.111E 02                -0.449E-02   0.647E-02   0.000E 00    0
0.111E 01  0.111E 02                -0.449E-02   0.980E-02   0.000E 00    0
0.111E 01  0.111E 02                 0.200E-02   0.980E-02   0.000E 00    0

    Z          U*                       STAB         Z/L          PLAW      ICODE
0.467E-01  0.354E 00                 0.472E 00   0.577E-02   0.167E 00    0
0.750E-01  0.409E 00                 0.507E 00   0.550E-02   0.192E 00    0
0.546E-01  0.342E 00                 0.443E 00   0.452E-02   0.187E 00    0
0.196E-02  0.216E 00                 0.507E 00   0.105E-01   0.120E 00    0
0.543E-02  0.175E 00                 0.552E 00   0.609E-02   0.116E 00    0
0.104E-01  0.222E 00                 0.372E 00   0.639E-02   0.150E 00    0
0.157E-02  0.171E 00                 0.375E 00   0.106E-01   0.100E 00    0
0.213E-03  0.158E 00                 0.455E 00   0.215E-01   0.895E-01    0
0.653E-05  0.124E 00                -0.445E 00  -0.349E-01   0.715E-01    0
0.545E-04  0.106E 00                -0.234E 00  -0.927E-02   0.604E-01    0
0.271E-03  0.213E 00                -0.354E 00  -0.135E-01   0.955E-01    0
0.111E 01  0.111E 02                -0.597E 00  -0.711E-03   0.277E-01    1
0.111E 01  0.111E 02                -0.982E 00  -0.447E-02   0.562E-01    1
0.111E 01  0.111E 02                -0.295E 00  -0.403E-03   0.455E-01    1
0.111E 01  0.111E 02                -0.262E 00  -0.254E-03   0.280E-01    1
0.111E 01  0.111E 02                 0.415E 00   0.840E-03   0.655E-01    0
0.111E 01  0.111E 02                 0.403E 00   0.832E-03   0.504E-01    0
0.662E-07  0.361E-01                 0.111E 01   0.374E 00   0.524E-01    0
0.481E-04  0.131E 00                 0.100E 01   0.129E 00   0.632E-01    0
0.304E-01  0.255E 00                 0.552E 00   0.844E-02   0.161E 00    0
0.377E 00  0.336E 00                 0.617E 00   0.657E-02   0.287E 00    0
0.712E-02  0.186E 00                 0.515E 00   0.502E-02   0.135E 00    0
0.570E 00  0.359E 00                 0.641E 00   0.337E-02   0.343E 00    0
0.559E 00  0.300E 00                 0.258E 01   0.397E-01   0.322E 00    0
```

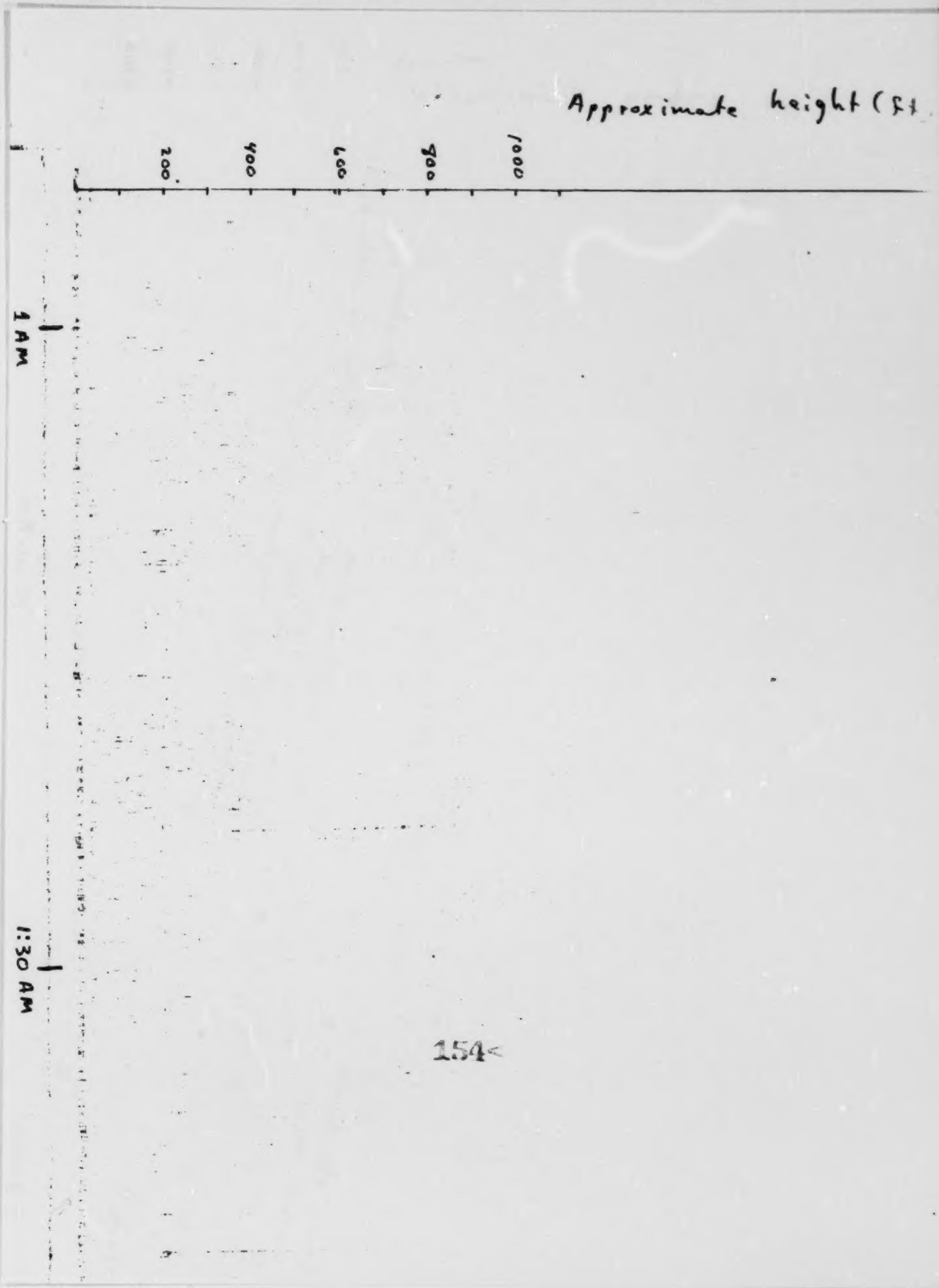
III. Acoustic sounder

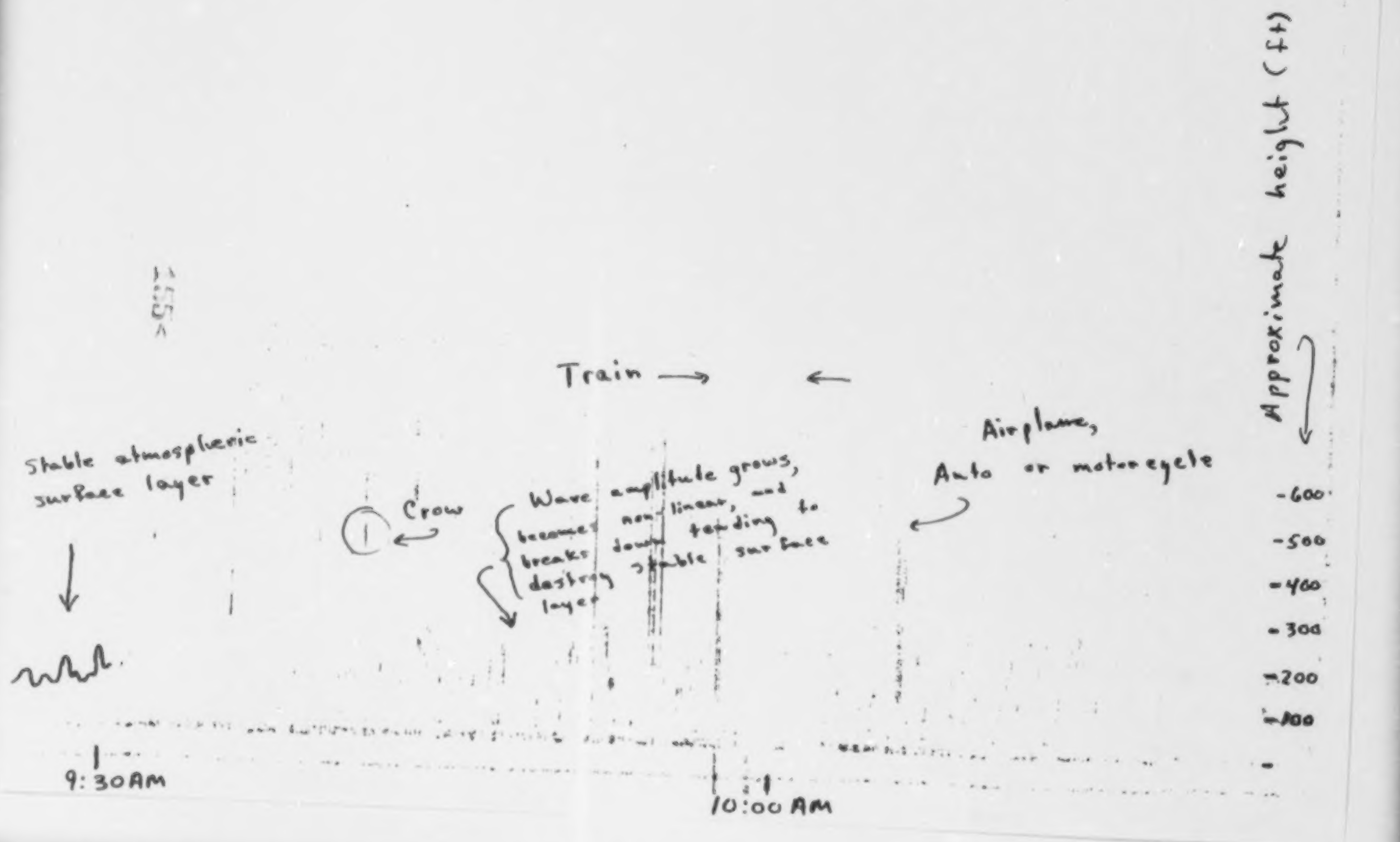
Final component redesign and adjustments were carried out during this period which put the sounder in an operational status. Initial probing was carried out from the roof of Coover Hall on the ISU campus. In spite of the very high ambient noise levels (60 dBA average with a range of 56 to 70 dBA) atmospheric echoes were observed from a ground based stable layer during an early morning observation period. No returns were observed during the day because of intolerably high ambient noise levels.

The instrument was then moved to the ERDA Ames Laboratory Nuclear Reactor site at the northwest edge of Ames since this location offered 28 dBA ambient noise levels with only occasional excursions to 50 dBA during passage of a train at a distance of about one-fourth mile. The low-noise environment allowed for a much higher gain to the receiver, considerably reduced background interference and therefore much more vivid displays of atmospheric motion and structure.

Two segments of the first returns observed at the Reactor site are shown on the following pages with some interpretation. (The photograph-like nature of the facsimile record does not permit very faithful reproduction by the copy machines. Photographs will be taken and supplied at a later date.) These returns agree very well with acoustic sounder observations from other laboratories. It has quickly become apparent to us that the atmosphere is a very capricious beast. It is apparent that the onset or break-up of stable conditions can occur within a matter of minutes. Furthermore, even during stable periods there is considerable "action" in the interfacial region. We are now studying various ways of quantifying results obtained from these records.

After the current testing period we are planning to operate the sounder in Des Moines. Preliminary sound-level measurements indicate the Fairgrounds


Approximate height (ft
200
400
600
800
1000
1 AM
1:30 AM


Approximate height (ft)
-600
-500
-400
-300
-200
-100
Stable atmospheric surface layer
① Crow
Wave amplitude grows, becomes non-linear, and breaks down tending to destroy stable surface layer
Train → ←
Airplane, Auto or motorcycle
9:30AM
10:00AM
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site to be optimum in terms of ambient noise. However, co-located sounder and balloon operations would provide some advantages for data analysis and interpretation. Final siting is still under consideration.

IV. Summary

Stability calculations are proceeding well with all of the basic analysis subroutines working satisfactorily. Synthesis of the various stability estimates and production of DEQ dispersion model stability input variables is now the major thrust of the stability assessment effort.

Acoustic sounder data is revealing the capricious and restless nature of the atmospheric planetary boundary layer. Measurements of inversion depths and mixing characteristics can now be made.

APPENDIX C

FINAL REPORT

Submitted to the

IOWA DEPARTMENT OF ENVIRONMENTAL QUALITY

on the

ASSESSMENT OF ATMOSPHERIC STABILITY CHARACTERISTICS

1 August 1975

Eugene S. Takle

Eugene S. Takle
Principal Investigator

Robert E. Post
Principal Investigator

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CONTENTS

I. Introduction

II. Stability calculations

III. Climatology of Iowa stability

IV. Acoustic sounder results

V. Photograph analysis

VI. Summary

I. Introduction

Determinations of hourly values of stability class for the period 1 November 1974 through 30 April 1975 have been made and submitted to DEQ.

The computer program used for this analysis was modified and used on a two year (1968-69) climatological data set from the ERDA meteorological tower. The results of this study represent the first detailed study of the seasonal and diurnal variability of atmospheric stability in Iowa.

Observations of dispersion of power plant plumes are being quantified and compared with calculated values of sigmas.

Acoustic sounder results are presented and current status is discussed. Funding provided by DEQ to Iowa State University under the SO_2 study has stimulated interest and financial assistance from other agencies to continue this type of work.

There is a clear indication of a continuing and expanding research program to study the dispersive properties of the atmosphere in Iowa.

II. Stability calculations

The stability calculations requested by DEQ have been carried out as outlined in the Second Quarterly Progress Report. Analysis of the November 1974 through April 1975 data and also the results for 1968 and 1969 (to be discussed in section III) show that of the various stability parameters, the wind profile power law, potential temperature gradient and Pasquill stability class were most reliable and readily available. Statistical tests on approximately 17000 hourly measurements for the years 1968-1969 were used to establish interrelationships among these variables. This will also be discussed in section III.

Data Acquisition

Most of the meteorological data necessary for the assessment of atmospheric stability are obtained from a 32 meter tower located about two miles northwest of the Iowa State University campus. This location provides information typical of central Iowa locations. Wind speed and temperature values at 2, 4, 8, 16, and 32 meters are recorded as ten minute averages each hour. Wind direction is recorded continuously at the 16 meter level. Additionally, insolation data are continuously recorded using an Eppley pyrheliometer at the Iowa State campus and cloud cover is observed hourly at the Des Moines airport.

Calculations

Stability class - The basic stability classification suggested by Pasquill (1962) is used. Whereas Pasquill's scheme designated stability classes as A through F, they now will be referred to as -3 through +2. The stability class 0 represents neutral conditions. These stability values are obtained in a manner similar to Turner's (1969), however, in the present study stability class is treated as a continuous rather than a discrete variable (Shir and Shieh, 1974). Daytime insolation intensities were determined in two ways. If solar radiation data were available, these were used in the following manner. Insolation values greater than 1.0 ly min^{-1} were considered strong, 0.58 to 1.0 ly min^{-1} as moderate, 0.33 to 0.58 ly min^{-1} as weak, 0.17 to 0.33 as a transition to/from daytime conditions, and less than 0.17 ly min^{-1} as a transition to/from nighttime. This is similar to the method used by Golder (1972), but also incorporates transition regions as suggested by Shir and Shieh (1974). If solar radiation data are not available for some particular time, solar altitude and observed cloud cover values are used to estimate insolation (Turner, 1969). At night observed cloud cover is used to account for variation in outgoing long wave radiation. Actual stability class values are then obtained by interpolation in Table 1 using observed eight meter wind speeds.

Table 1. Matrix used to determine stability class values*

8m wind speed ($m\ sec^{-1}$)	DAY			TRANSITION		NIGHT	
	Incoming Solar Radiation			To/From Daytime	To/From Nighttime	Clouds	
	Strong	Moderate	Weak			> 4/8	< 4/8
0-2	-3.5 to -3.0	-3.0 to -2.2	-2.5 to -2.0	-1.5 to -0.5	1.5 to 0.5	1.6 to 1.5	2.6 to 2.5
2-3	-3.0 to -2.2	-2.2 to -2.0	-2.0 to -1.0	-1.0 to -0.3	1.0 to 0.5	1.5 to 0.6	2.5 to 1.6
3-5	-2.2 to -1.5	-2.0 to -1.0	-1.0 to -0.5	-0.6 to -0.2	0.5 to 0.3	0.6 to 0.3	1.6 to 0.5
5-6	-1.5 to -1.0	-1.0 to -0.3	-0.5 to -0.2	-0.3 to -0.1	0.4 to 0.2	0.3 to 0.1	0.5 to 0.3
6-8	-1.0 to -0.3	-0.3 to -0.1	-0.2 to 0.0	-0.2 to 0.0	0.2 to 0.0	0.1 to 0.0	0.3 to 0.1
> 8	-0.3	-0.1	0.0	0.0	0.0	0.0	0.1

---

* See Turner (1969) for complete explanation

Table 2. Estimates of stability class from Richardson number (Ri) and Monin Obhukov length (L)

Stability category	Ri (at $z_1 = 2$ m)	L,m
A (-3)	-1.0 to 0.7	-2 to -3
B (-2)	-0.5 to -0.4	-4 to -5
C (1)	-0.17 to -0.13	-12 to -15
D (0)	0	∞
E (1)	0.03 to 0.05	35 to 75
F (2)	0.05 to 0.11	8 to 35

Power law exponent - If the wind velocity profile in the atmospheric boundary layer is assumed to conform to a power law relationship, then the following relationship holds:

$$\frac{u_1}{u_2} = \left(\frac{z_1}{z_2} \right)^{\beta}$$

The exponent, β , carries information about the stability within the layer z_1 to z_2.

Calculated values of β from all possible combinations of tower levels are averaged using a system of weighting factors. These weighting factors place less emphasis on the low, shallow layers (e.g. from 2 to 4 meters) since less confidence can be placed in the wind speeds at the lower levels due to surface effects.

Potential temperature gradient - Estimates of the low level potential temperature gradient were calculated by assuming a linear distribution between two tower levels. Values for the 2 to 16 meter and 2 to 32 meter layers were determined. The results obtained from the latter layer will be presented in the next section.

Sigma values (σ_y and σ_z) - These values give an indication of the diffluent nature of a plume within the atmospheric boundary layer. A plume will tend to spread more in the cross wind (y) and vertical (z) directions during unstable periods and less during periods of greater stability.

The standard deviation of the azimuth angle, σ_a, can be estimated by taking one-sixth of the total deviation, in degrees, of the 16 meter wind direction over a one hour period.

ASME (1973) gives relationships for the standard deviation of the elevation angle, σ_e, as:

$$\sigma_e = 0.2\ \sigma_a \quad \text{stable}$$

$$\sigma_e = 0.7\ \sigma_a \quad \text{unstable}$$

It is necessary to adjust these standard deviations to source height. A power law method suggested by ASME (1973) can be used,

$$\sigma_{a_h} = \sigma_{a_{16m}} \left(\frac{h}{16} \right)^{-\beta}$$

$$\sigma_{e_h} = \sigma_{e_{16m}} \left(\frac{h}{16} \right)^{-\beta} ,$$

where β is the power law exponent discussed before and h is the source height. ASME (1973) also suggested equations for the final determination of σ_y and σ_z:

$$\text{stable case} \quad \begin{cases} \sigma_y = 0.15\ \sigma_a\ x^{0.71} \\ \sigma_z = 0.15\ \sigma_e\ x^{0.71} \end{cases}$$

$$\text{unstable case} \quad \begin{cases} \sigma_y = 0.045\ \sigma_a\ x^{0.86} \\ \sigma_x = 0.045\ \sigma_e\ x^{0.86} \end{cases}$$

All values for σ_y and σ_z were calculated for a downwind distance, x, of 100 meters. This distance, although somewhat arbitrary, is a convenient distance for comparisons to photographically determined values.

Effective stack height temperature

The ambient temperature at effective stack height was calculated in one of three ways depending on atmospheric stability as determined from Richardson number (see subroutine PLUMET).

i) stable:

T (ambient) = T (2m)

ii) neutral:

T (ambient) = T (2m) - 0.0098 (H - 2 + ΔH)

where T is °C and stack height H in m.

iii) unstable:

$T\ (\text{ambient}) = T\ (2\text{m}) - 0.013\ (H - 2 + \Delta H)$, if plume rise is 100m or less, $T\ (\text{ambient}) = T\ (2\text{m}) - 0.013\ (98) - 0.0098\ (H - 2 + \Delta H - 98)$, if plume rise is greater than 100m, where T in °C, stack height H in m, plume rise ΔH in m.

In the absence of an external plume rise value, ΔH was set equal to 100m.

The computer output giving the hourly calculations for the SO_2 study and have been delivered to Mr. Dennis Vaughn for use in the DEQ dispersion models. A complete listing of all materials generated is given in the following two pages.

Available Output

(1) Graphical output (1968 and 1969)

- A. 8 1/2 x 11
  - 1. Annual averages of diurnal variation
    - a. Stability class
    - b. Potential temperature gradient
    - c. Power law exponent
    - d. Sigma y
    - e. Sigma z
  - 2. Annual, January, April, July, and October averages of diurnal variation
    - a. Stability class
    - b. Potential temperature gradient
    - c. Power law exponent
- B. 11 x 14 (computer size)
  - 1. Monthly and annual averages of diurnal variation
    - a. Richardson number
    - b. Reciprocal of Monin-Obhukov length (from Ri)
    - c. Reciprocal of Monin-Obhukov length (from stability class)
    - d. Stability class
    - e. Power law exponent
    - f. Potential temperature gradient
    - g. Sigma y
    - h. Sigma z

(2) Punched card output

- A. 1968 and 1969
  - 1. Tower data
  - 2. Solar radiation data (ly/hr)
  - 3. Cloud cover data (3 hrly obs)
  - 4. All information in (1) B. above

B. November 1974 to April 1975

1. Tower data
2. Cloud cover data (hrly obs)

(3) Printed output

A. Individual hourly values

1. Richardson number
2. Richardson number (assumes wind speed = 0 at sfc)
3. Stability class
4. 1/L (from stability class)
5. 1/L = f(z) for 23, 64, 96, 218m (from both Ri)
6. Surface roughness height (zo)
7. Friction velocity (u*) for neutral cases only
8. Eddy diffusivity
9. Power law exponent
10. Effective stack height temperature (effective stack height = 100m until plume rise relationship is arrived at)
11. Sigma a
12. Sigma y (Cramer)
13. Sigma y (ASME)
14. Sigma z (Cramer)
15. Sigma z (ASME)

B. All information in (1) B. above

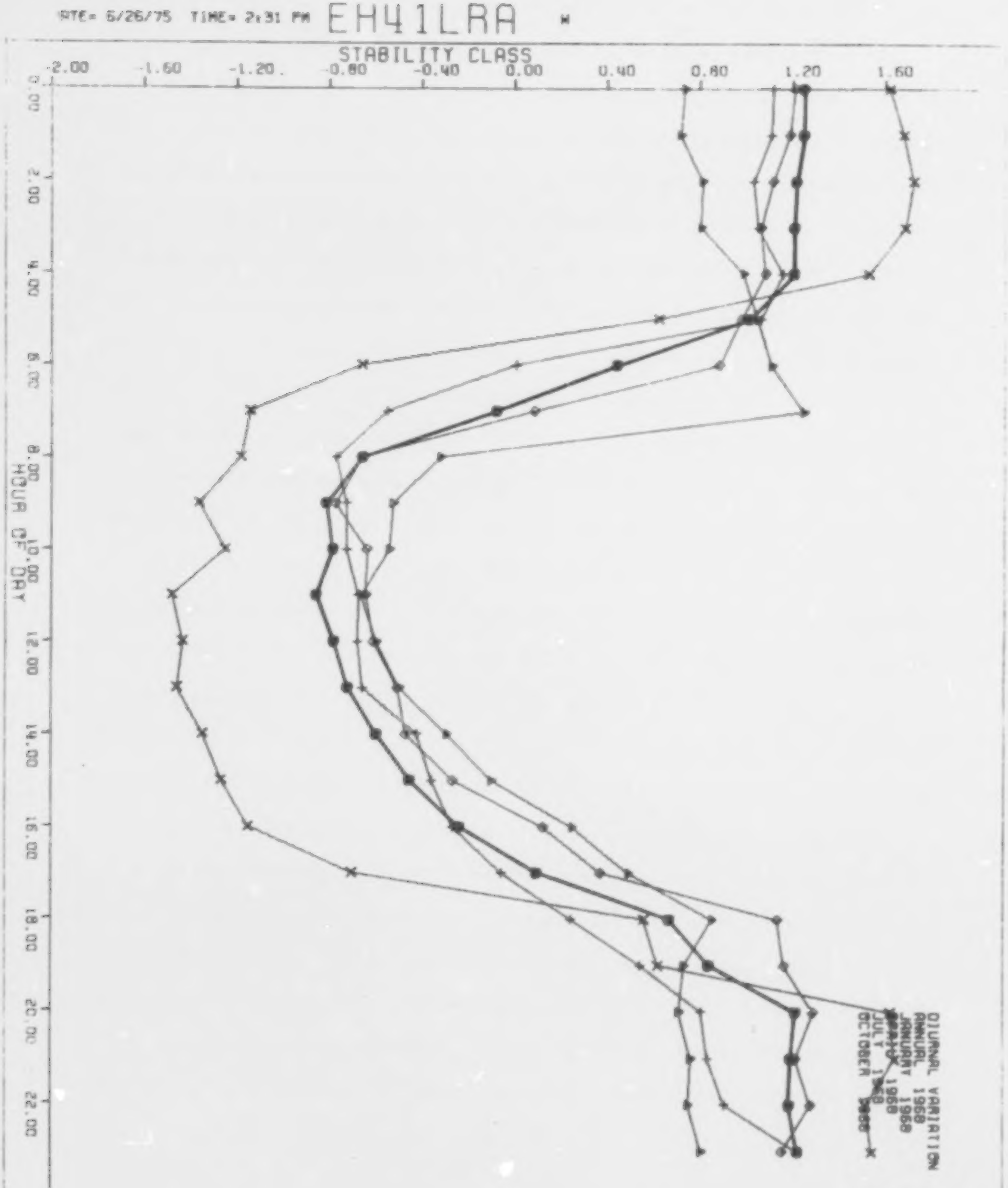
III. Climatology of Iowa stability

The techniques assembled for studying atmospheric stability as outlined in the Second Quarterly Progress Report and section II of this report were applied to two years (1968-1969) of hourly measurements from the ERDA meteorological tower. The results of this study will provide useful information for the modeling of atmospheric dispersion any time of year.

The five variables described in the preceding section were determined from the hourly data for 1968 and 1969. Monthly and annual averages of diurnal variation were calculated and plotted. The following is a discussion of some of the more important features of those plots.

There are some common features evident in the curves for power law exponent, stability class, and potential temperature gradient (see Figures 1 through 6). All show a large dip towards unstable conditions during the day. The curves for January are typically less stable at night as well as less unstable during the day than the other months. Additionally, July values are predominately more stable at night and more unstable during daytime periods. The effect of varying daylength during the year can be seen from the monthly curves. The transition from stable (unstable) to unstable (stable) values is later (earlier) in the day for January values and the opposite is true for July.

Stability class - From Figures 1 and 2 one should note the significant seasonal variability over the entire 24 hour period. Increased insolation during the summer months produces greater daytime instability. Climatologically, July has less cloud cover and lighter winds than January (U.S. Department of Commerce, 1968). Increased periods of relatively cloudless skies with light winds would account for the highly stable (unstable) average values found during July nighttime (daytime) periods. Increased cloudiness and winds tend


DATE= 6/26/75 TIME= 2:31 PM EH41LRA
STABILITY CLASS
-2.00
-1.60
-1.20
-0.80
-0.40
0.00
0.40
0.80
1.20
1.60
HOUR OF DAY
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
DIURNAL VARIATION
ANNUAL 1968
JANUARY 1968
APRIL 1968
JULY 1968
OCTOBER 1968

169<

Figure 1

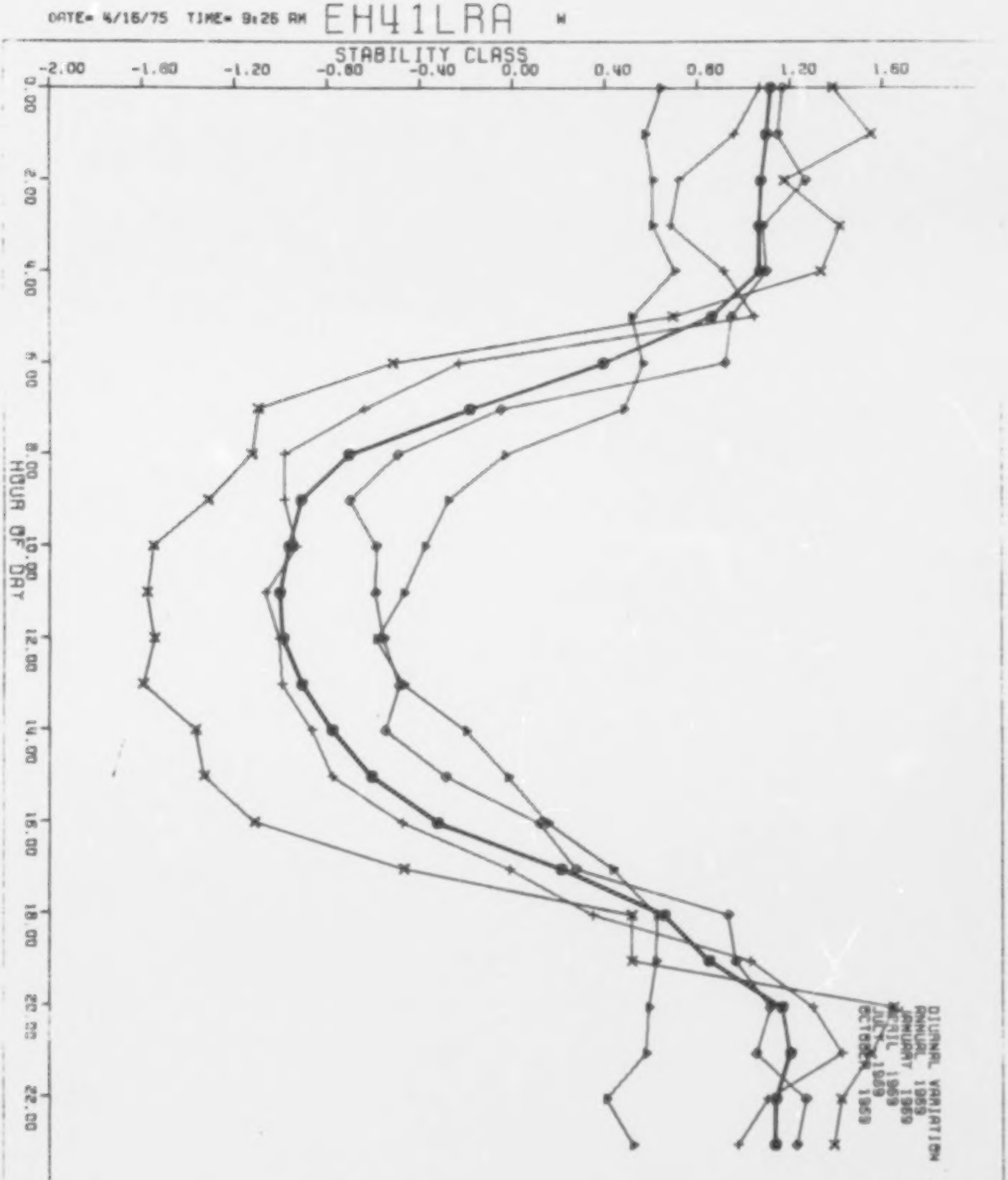

DATE= 4/16/75 TIME= 9:26 AM EH41LRA
STABILITY CLASS
-2.00
-1.60
-1.20
-0.80
-0.40
0.00
0.40
0.80
1.20
1.60
HOUR OF DAY
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
DIURNAL VARIATION
ANNUAL 1969
JANUARY 1969
APRIL 1969
JULY 1969
OCTOBER 1969

Figure 2

170<

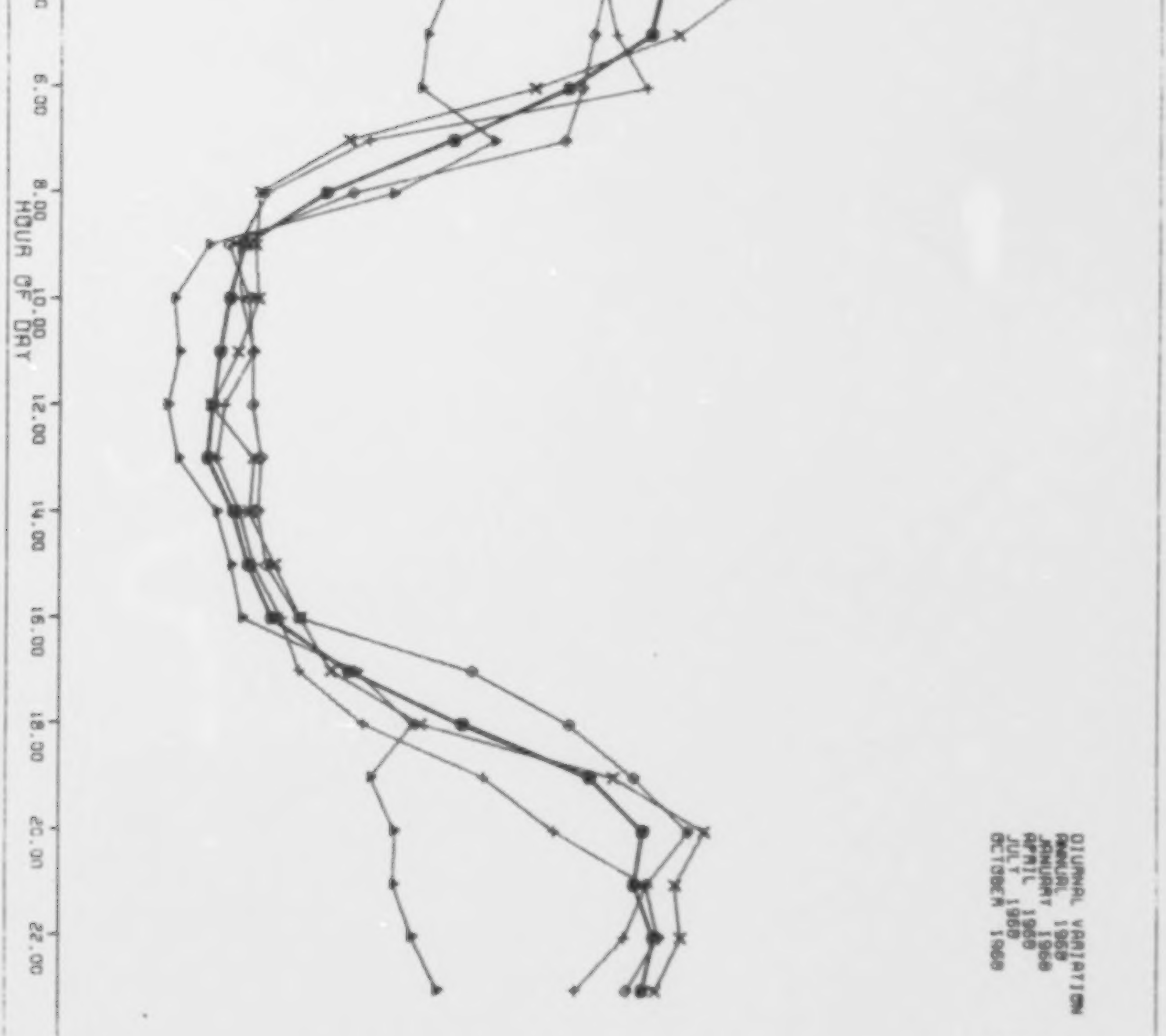

POWER LAW EXPONENT (x10⁻¹)
0.40
0.80
1.20
1.60
2.00
2.40
2.80
3.20
3.60
4.00
HOUR OF DAY
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
DIURNAL VARIATION
● ANNUAL 1968
▲ JANUARY 1968
+ APRIL 1968
X JULY 1968
◆ OCTOBER 1968

Figure 3

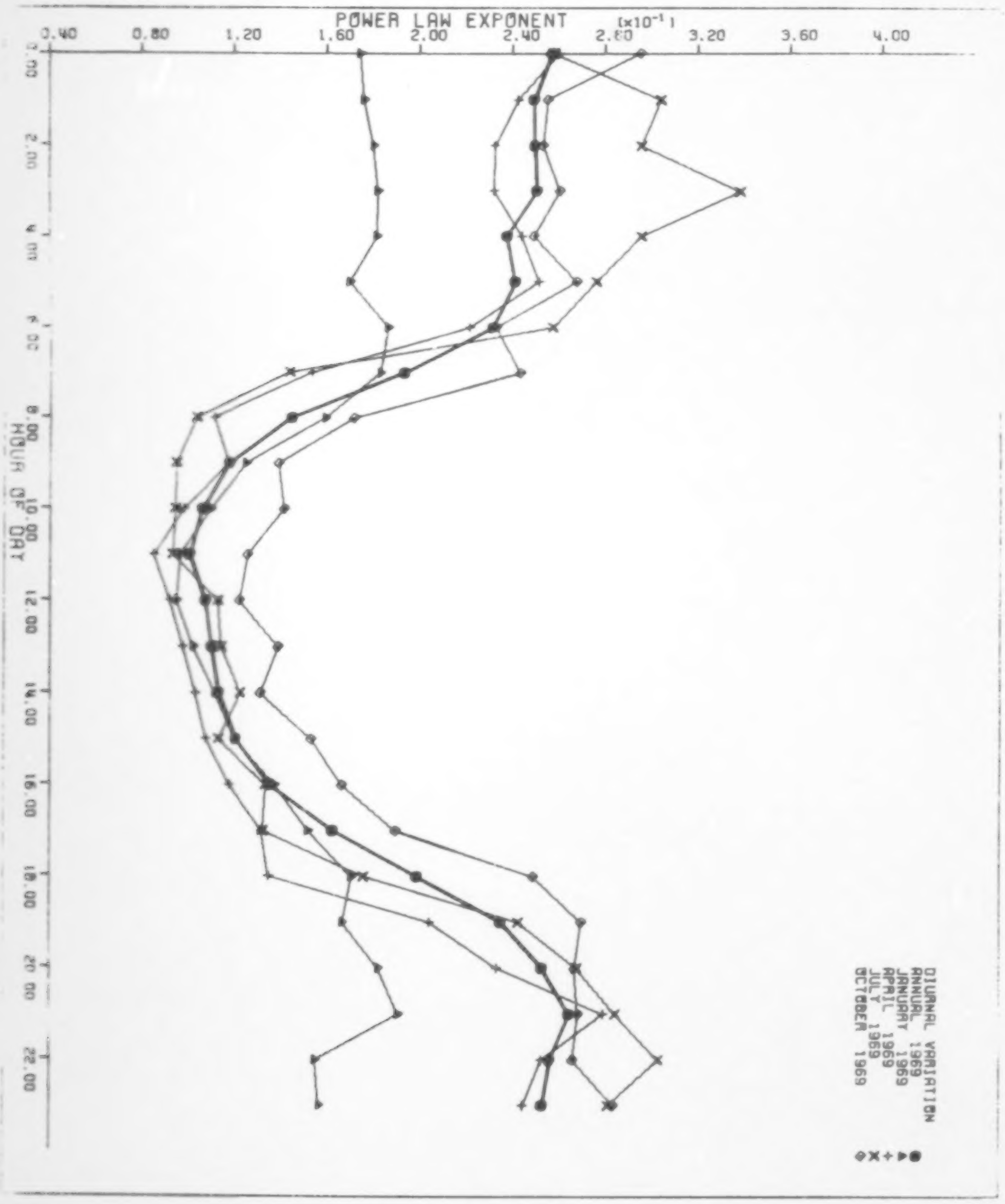

POWER LAW EXPONENT (x10⁻¹)
0.40
0.80
1.20
1.60
2.00
2.40
2.80
3.20
3.60
4.00
HOUR OF DAY
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
DIURNAL VARIATION
ANNUAL 1969
JANUARY 1969
APRIL 1969
JULY 1969
OCTOBER 1969

Figure 4

172<

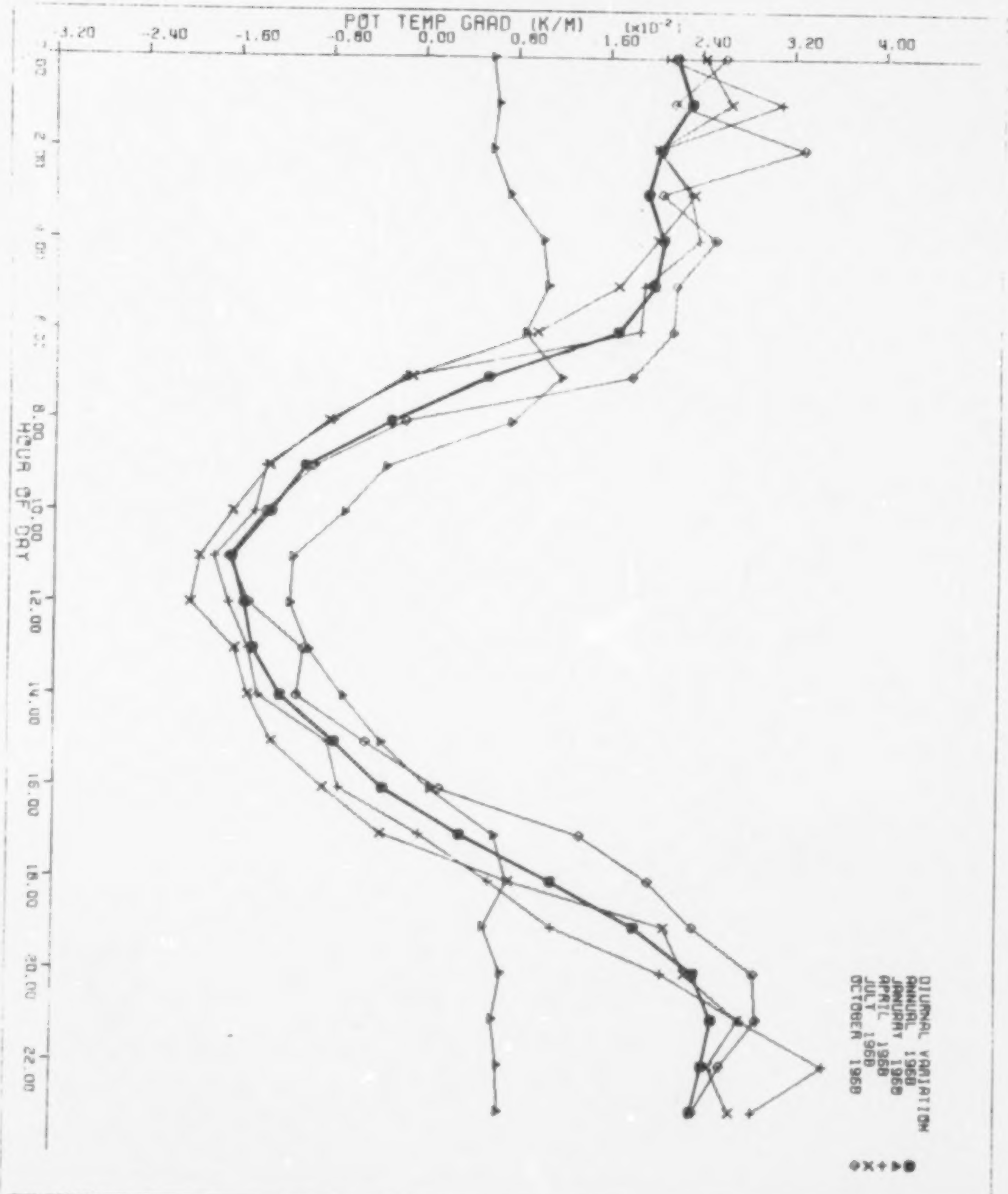

POT TEMP GRAD (K/M) (x10^{-2})
-3.20
-2.40
-1.60
-0.80
0.00
0.80
1.60
2.40
3.20
4.00
HOUR OF DAY
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
DIURNAL VARIATION
● ANNUAL 1968
▶ JANUARY 1968
+ APRIL 1968
X JULY 1968
◇ OCTOBER 1968

Figure 5

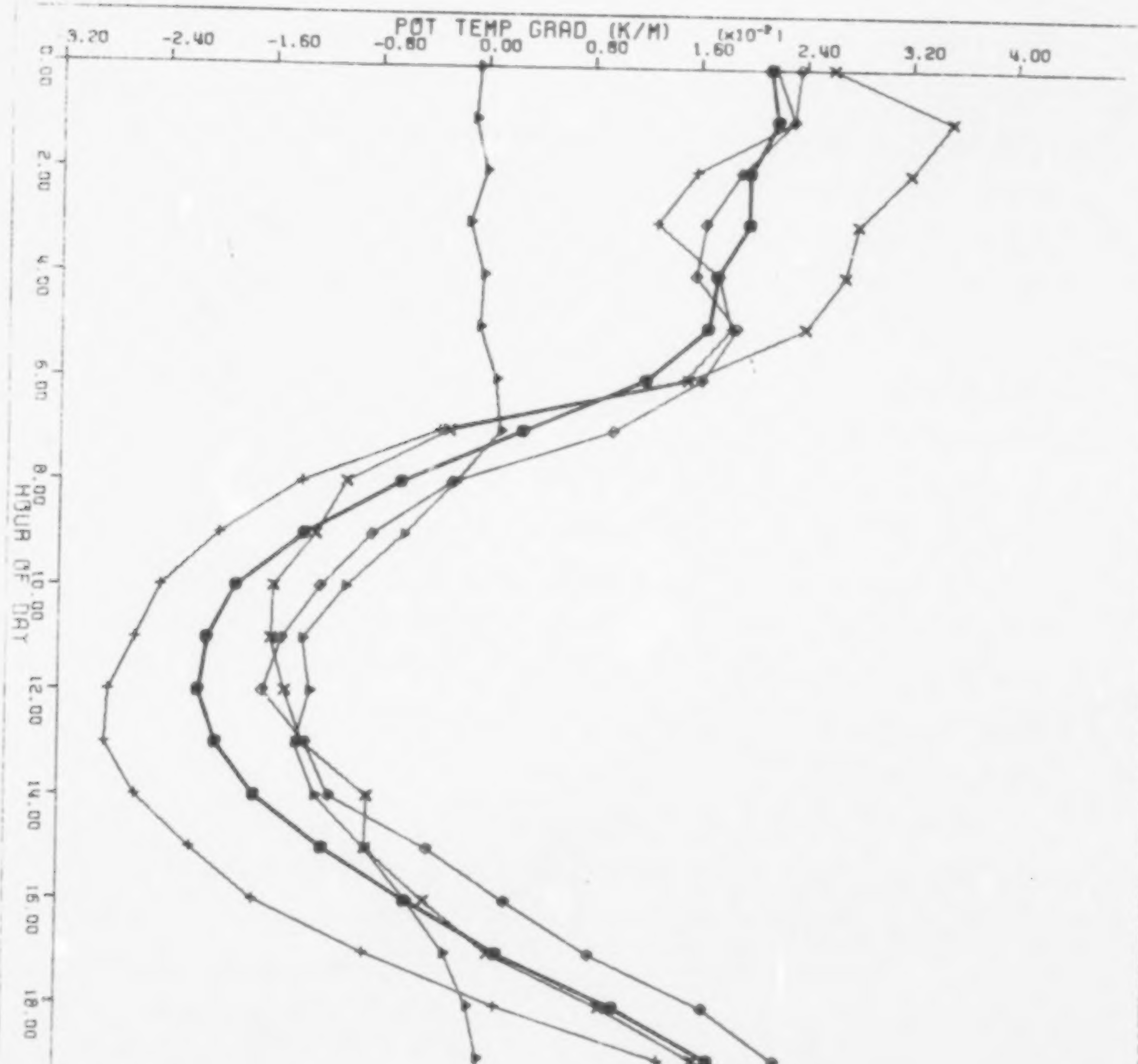

POT TEMP GRAD (K/M) (x10^{-2})
-3.20
-2.40
-1.60
-0.80
0.00
0.80
1.60
2.40
3.20
4.00
HOUR OF DAY
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
DIURNAL VARIATION
ANNUAL 1969 ●
JANUARY 1969 ▲
APRIL 1969 +
JULY 1969 X
OCTOBER 1969 ◆

Figure 6

174<

to have a moderating effect in January. The transition from stable to unstable conditions seems to be systematically much more rapid than the reverse transition.

Power law exponent - The seasonal variability shown in Figures 3 and 4 is much more pronounced during nighttime stable periods than daytime unstable periods. The unstable periods are characterized by only small changes of wind speed with height. During stable periods, however, the flow tends to be laminar in form and the low level winds decouple from winds aloft. The wind shear (and thus power law exponent) will increase as the layer becomes increasingly stable.

Potential temperature gradient - From Figures 5 and 6 we can see a significant seasonal variability during nearly all hours of the day. The large dip in the April curve in Figure 6 seems to be a real anomaly when compared to the similar, but not as extreme, deviation of the April power law exponent curve in Figure 4. The modifying influence of increased cloud cover and winds during January as compared with the other months can again be seen.

In Figures 7 through 12 the annual variation of the above three variables for 1968 and 1969 are plotted separately. In both years the stability class values leads the other two variables by about 30 to 60 minutes during the morning transition from stable to unstable conditions. This observation is not unreasonable as the stability class is based directly on solar radiation whereas power law exponent and potential temperature gradient values are resulting manifestations of variable insolation.

Sigma values - Figures 13 through 16 include curves of the annual averages of the diurnal variation of sigma-y and sigma-z at 100 meters downstream from a point source for 1968 and 1969. Sigma-y is seen to vary only slightly during

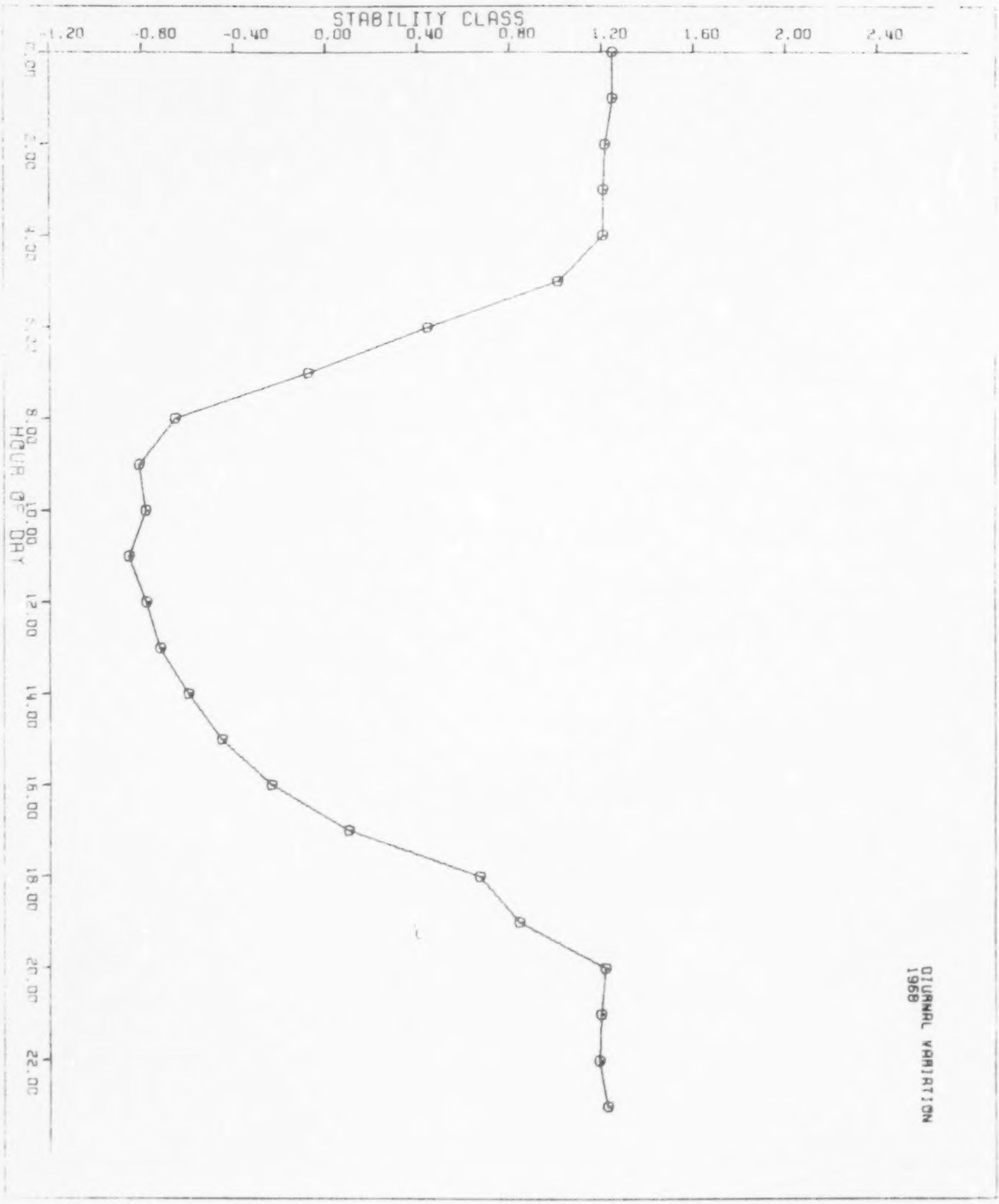

STABILITY CLASS
-1.20
-0.80
-0.40
0.00
0.40
0.80
1.20
1.60
2.00
2.40
HOUR OF DAY
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
DIURNAL VARIATION
1968

Figure 7

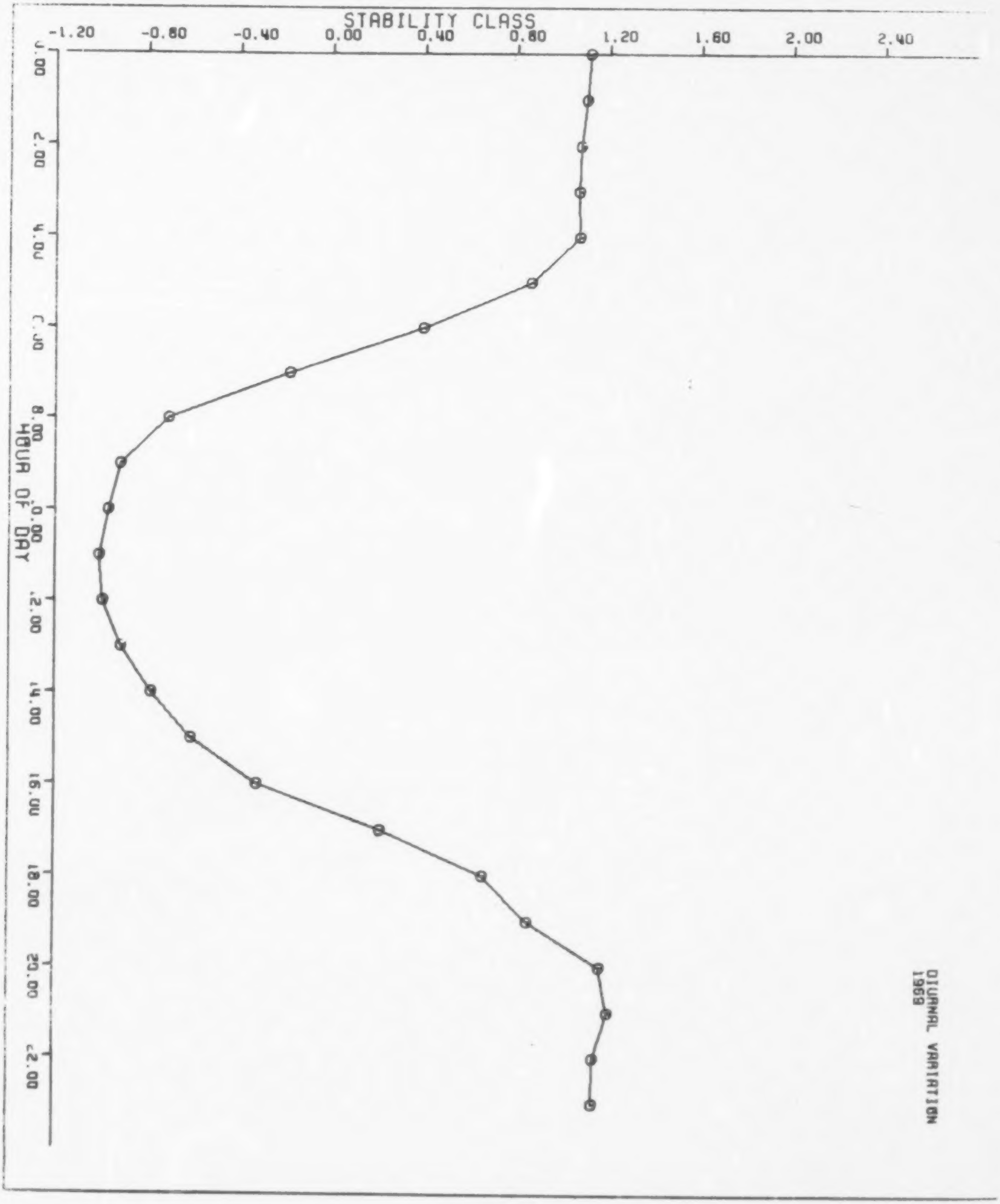

STABILITY CLASS
-1.20
-0.80
-0.40
0.00
0.40
0.80
1.20
1.60
2.00
2.40
HOUR OF DAY
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
DIURNAL VARIATION
1969

Figure 8

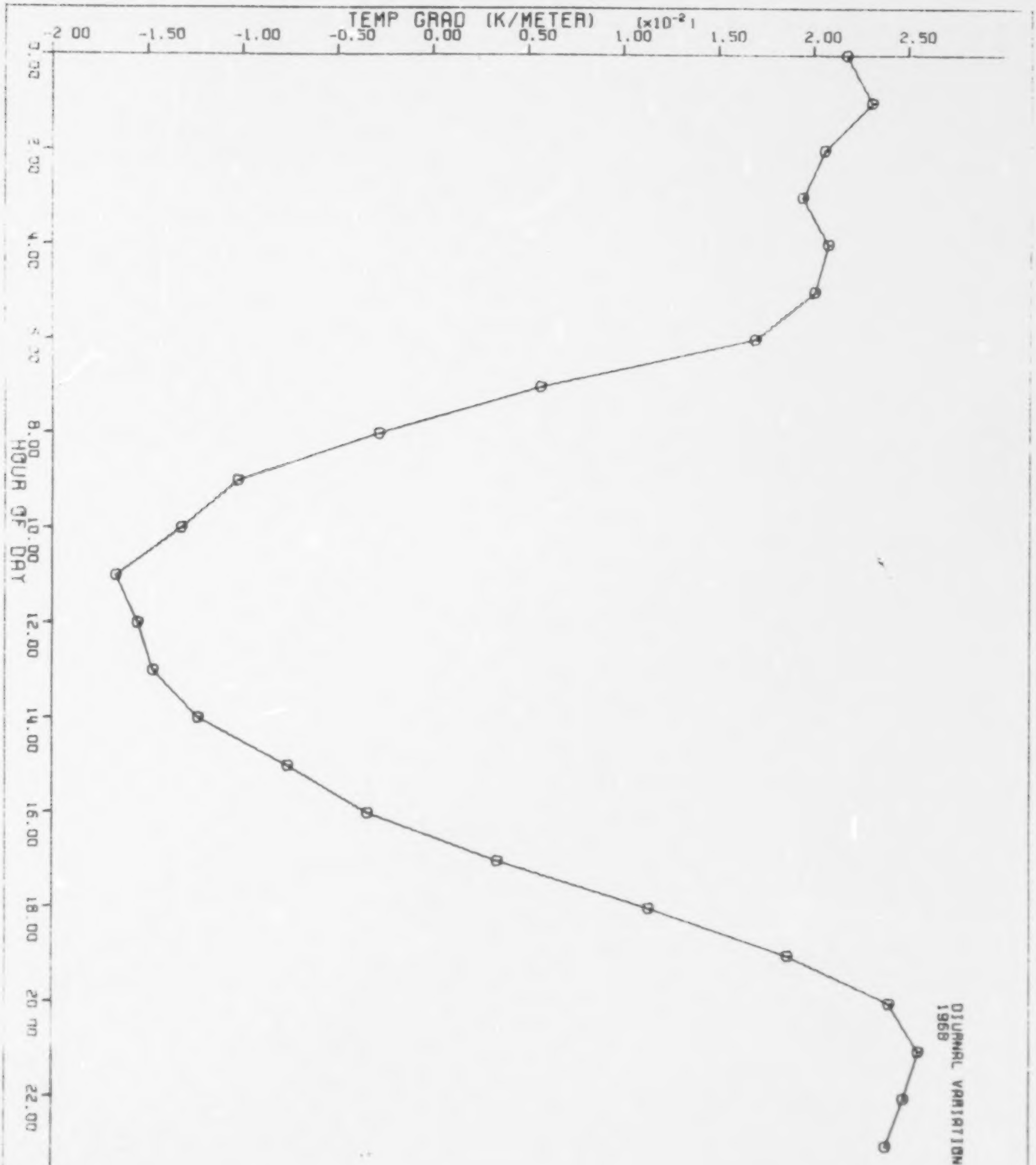

TEMP GRAD (K/METER) (×10⁻²)
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
2.50
HOUR OF DAY
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
DIURNAL VARIATION
1968

Figure 9

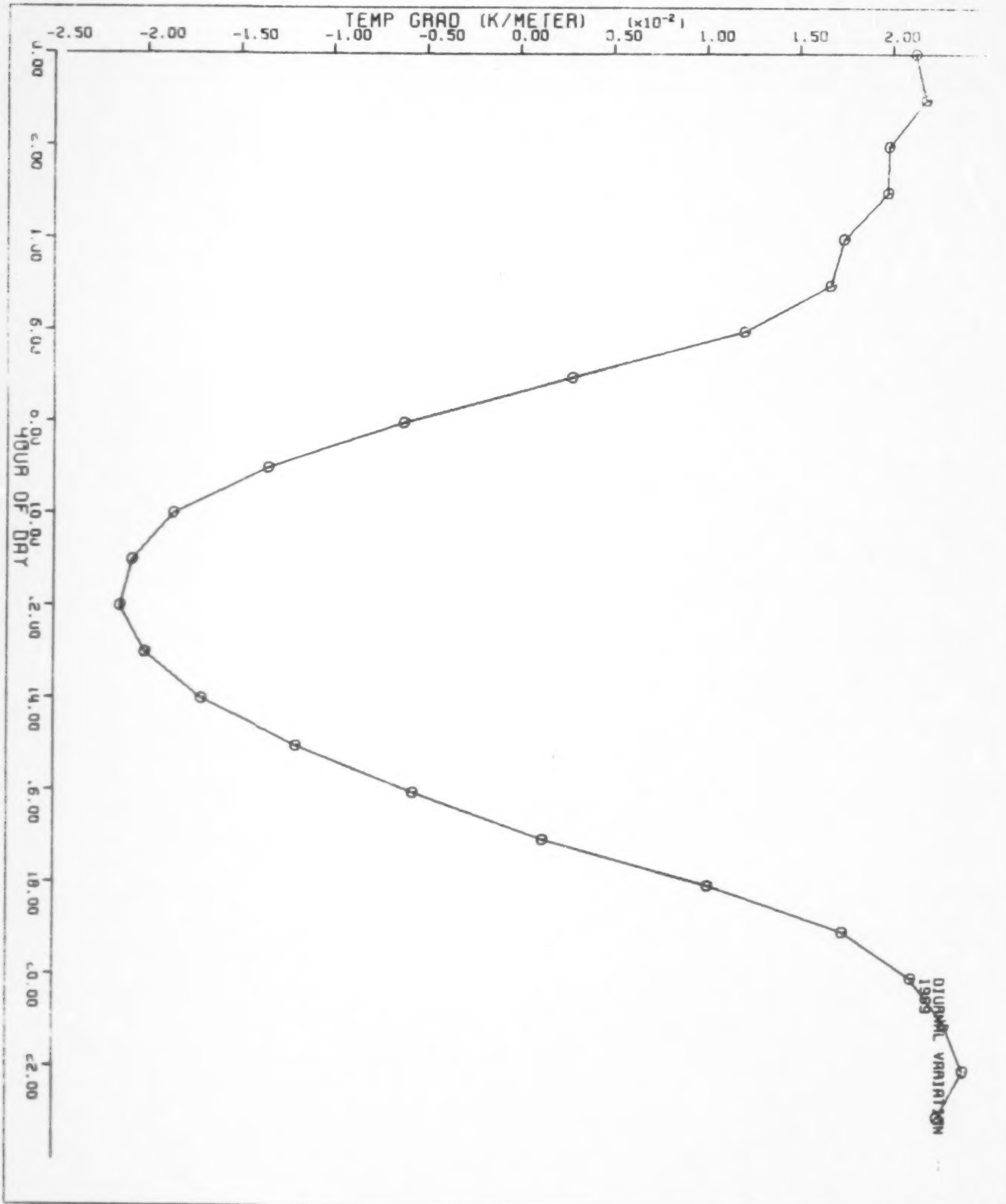

TEMP GRAD (K/METER) (×10⁻²)
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
HOUR OF DAY
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
DIURNAL VARIATION
1969

Figure 10

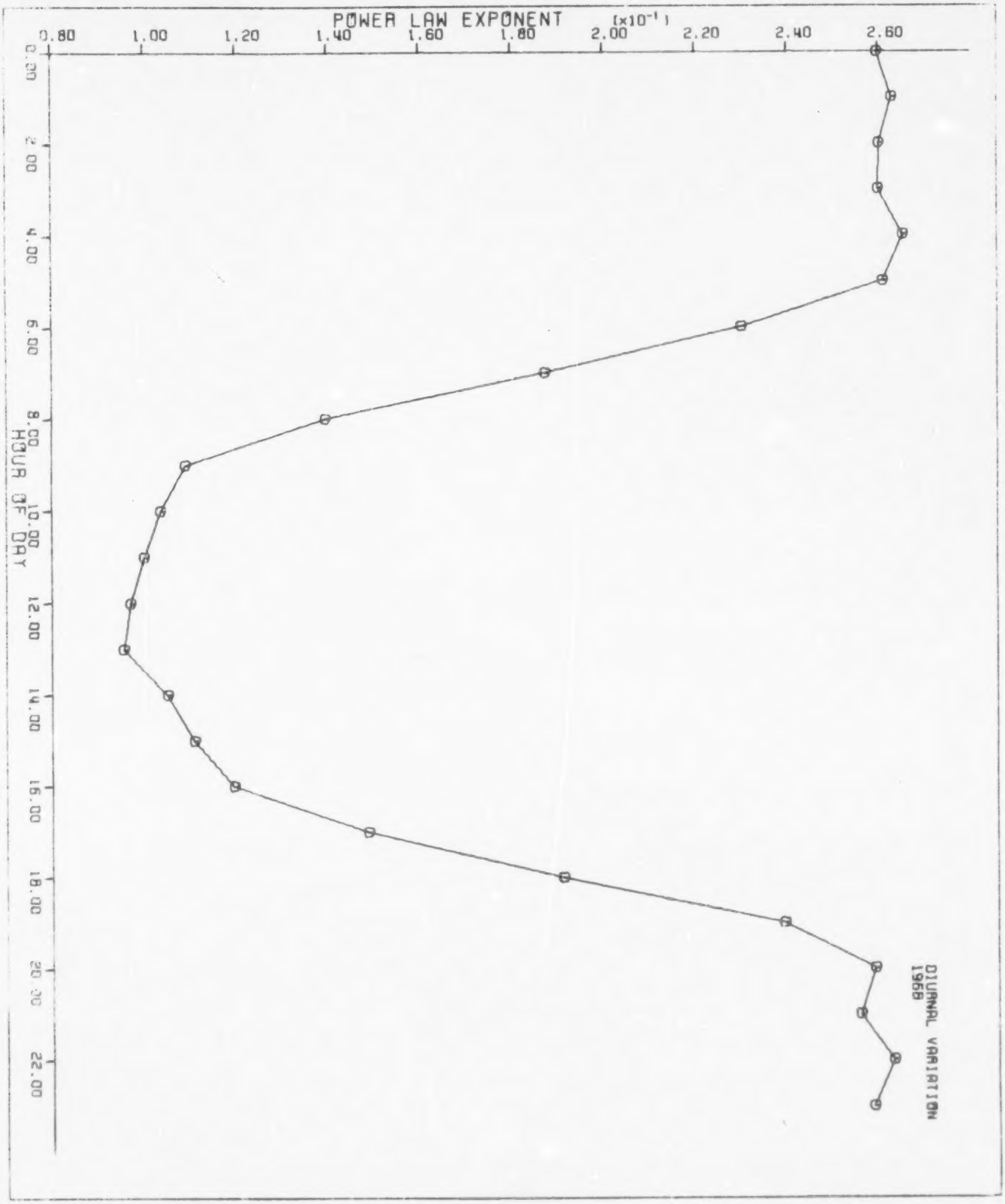

POWER LAW EXPONENT
(x10^{-1})
0.80
1.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
2.60
HOUR OF DAY
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
DIURNAL VARIATION
1968

Figure 11

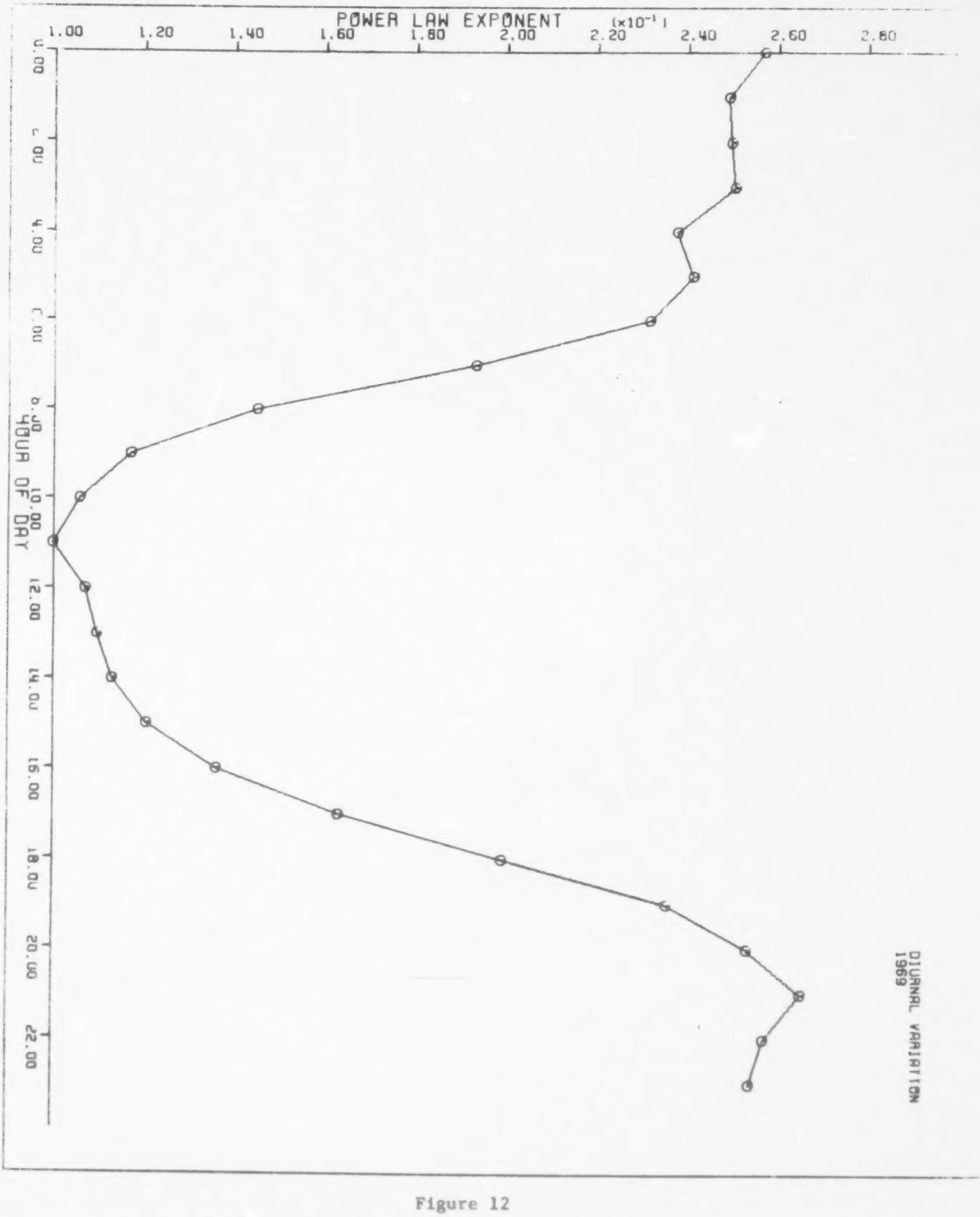


Figure 12

161

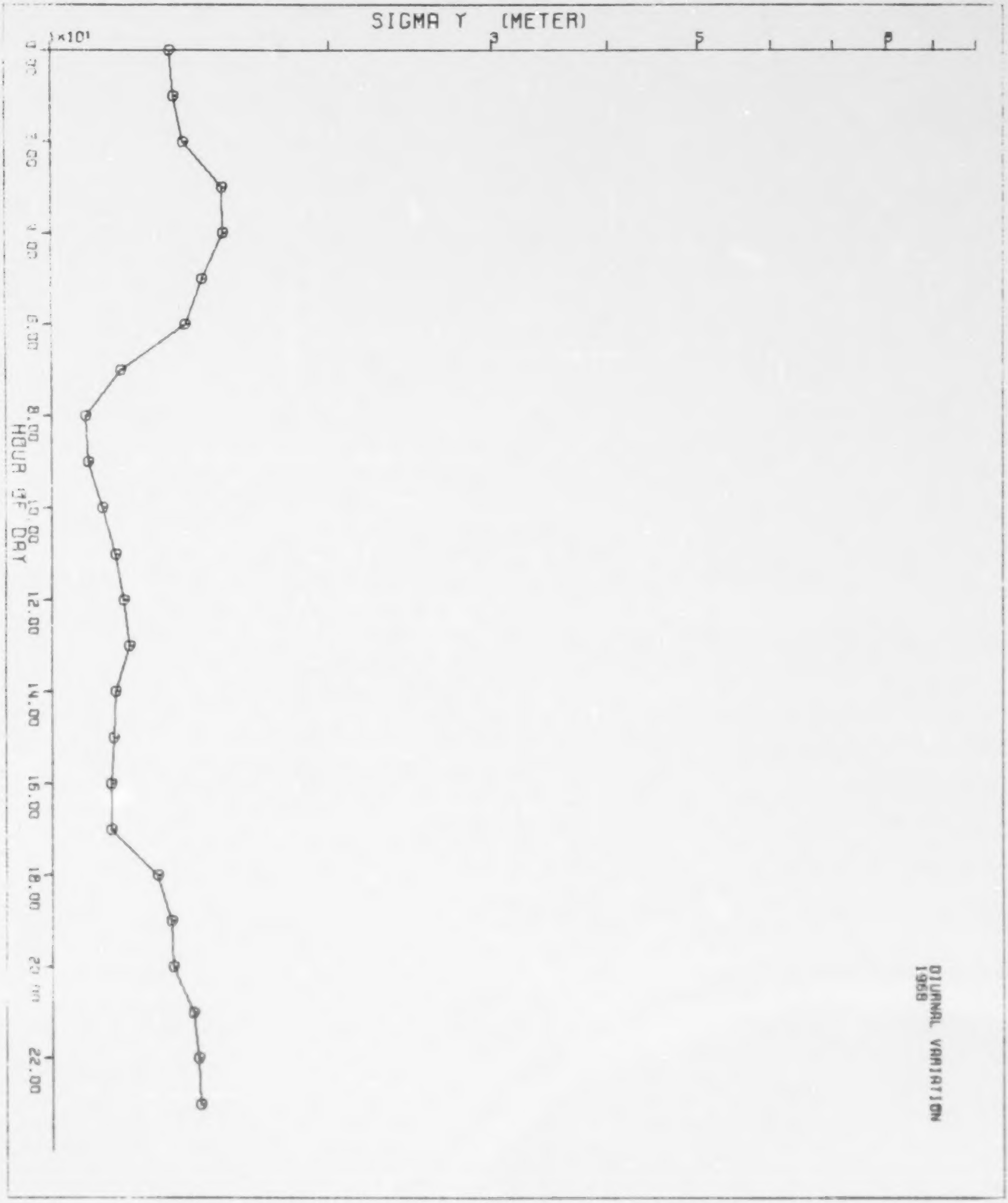


Figure 13

182<

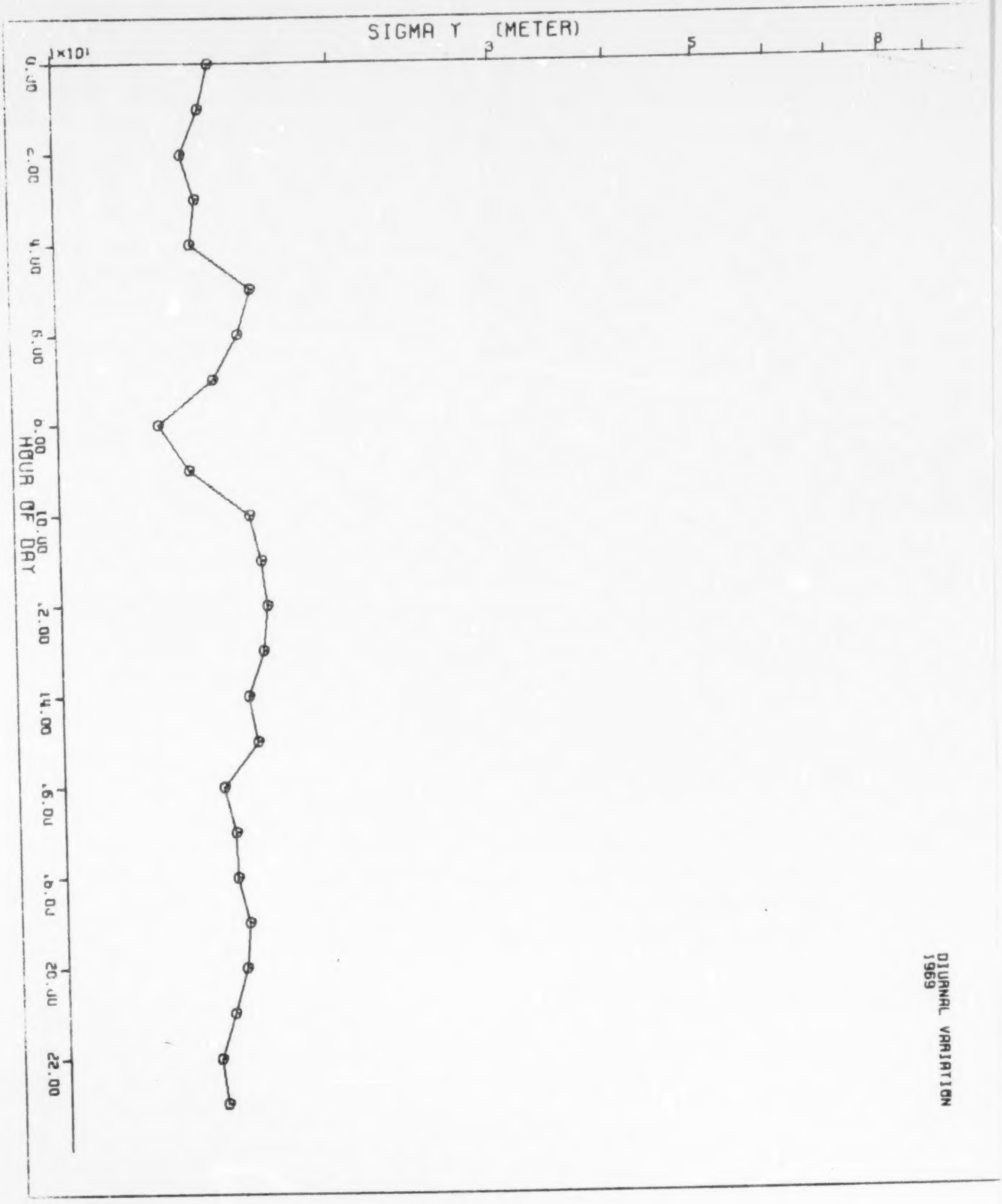

SIGMA Y (METER)
×10¹
3
5
8
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
HOUR OF DAY
DIURNAL VARIATION
1969

Figure 14

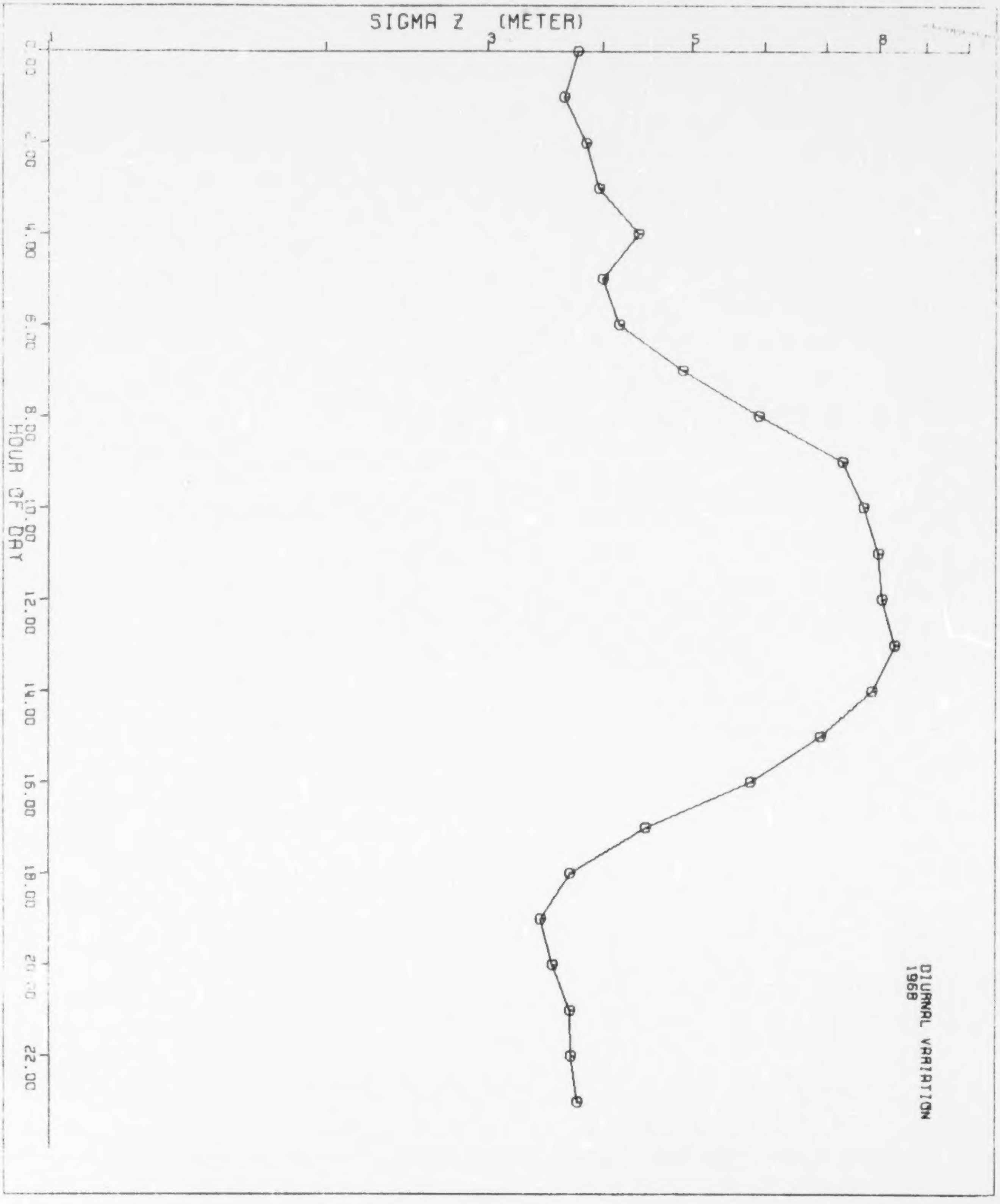

SIGMA Z (METER)
1
3
5
8
HOUR OF DAY
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
DIURNAL VARIATION
1968

Figure 15

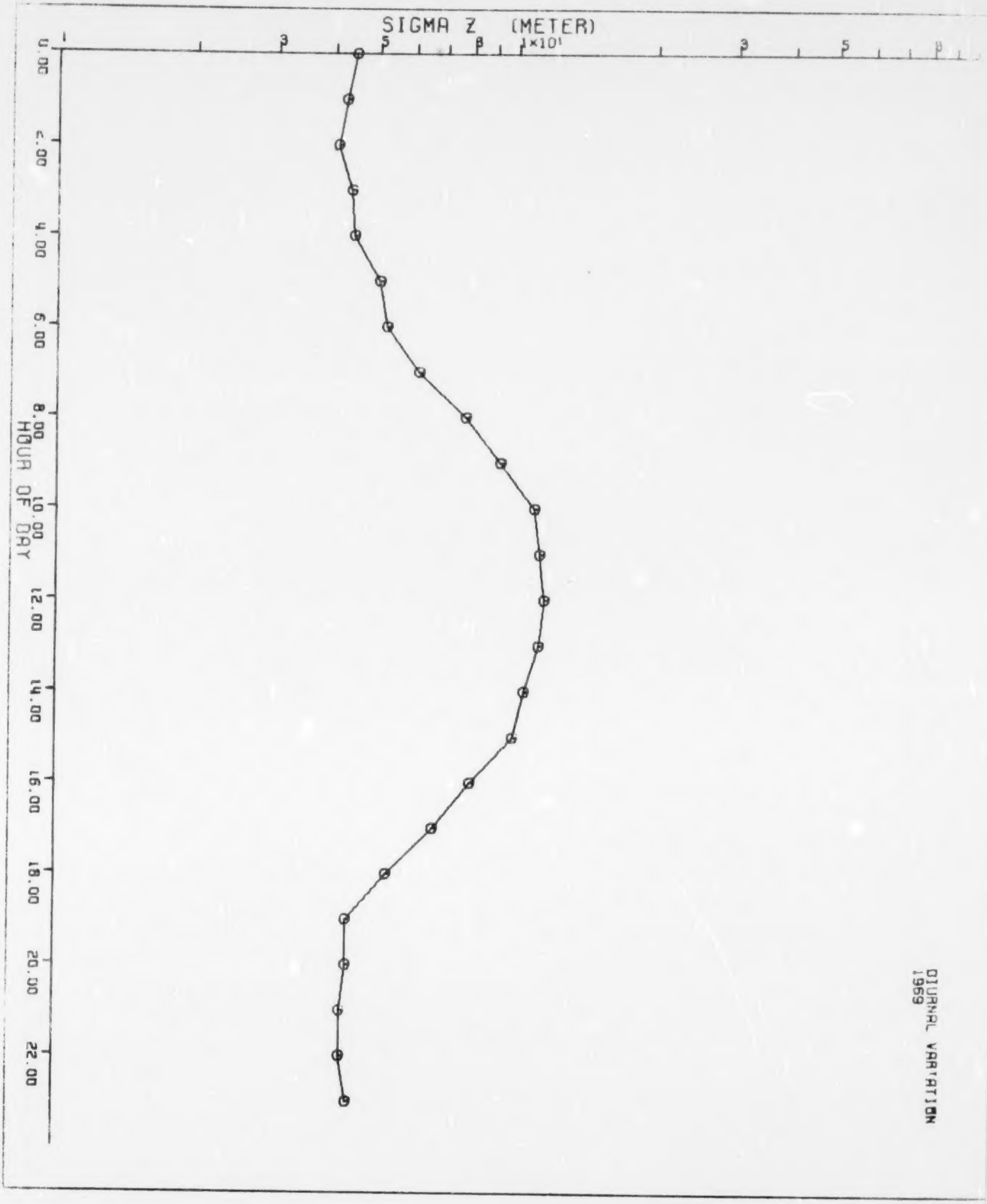


Figure 16

185<

the entire 24 hour period and is essentially independent of stability conditions. The values of sigma-z show a significant hump during the daytime hours indicating greater plume depths. Conditions of greater instability lead to increased mixing in the vertical and therefore larger values of sigma z. The range of sigma z is from about four meters during stable periods to a maximum of about nine or ten meters during the most unstable period of the day.

As a final note on the results of this study, we should point out the highly consistent nature of all calculated variables. The three variables chosen for thorough study (i.e., stability class, power law exponent, and potential temperature gradient) are determined from independent input data. Comparisons of these three variables reveal that in most cases the same type of atmospheric structure is indicated. Correlations of the annually averaged hourly values of the three taken in pairs were all in excess of 0.97. This outcome gives added confidence that the variables are characterizing the atmospheric structure properly. Isolated situations, however, may not exhibit this high correlation, particularly during the transition periods discussed previously.

IV. Acoustic sounder results

The acoustic sounder has been and will continue operating in a continuous mode. Typical results are shown in Figures 1-6 of the following two pages. In each of thse figures vertical axis represents height above the earth's surface in meters. The top of the record is 1000 m. The horizontal axis is the time axis with 15 minutes between hash marks except Figure 3 which is marked every minute.

Dark regions represent acoustic returns, not all of which are due to atmospheric motions or structure. In Figure 1, for instance, the darker region

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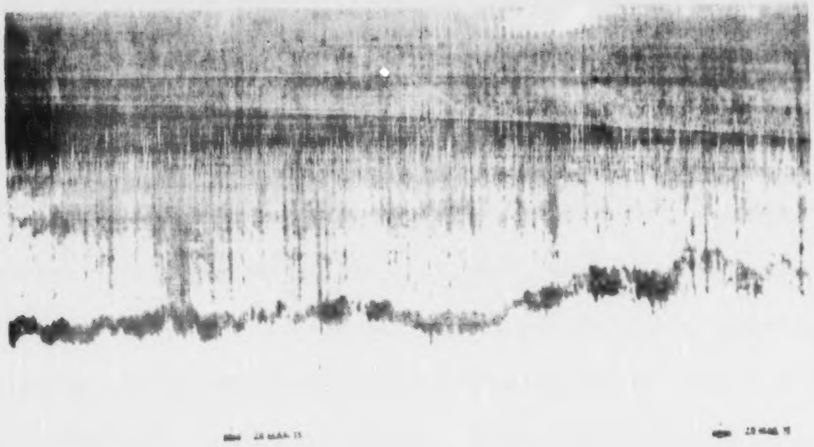


FIG. 1

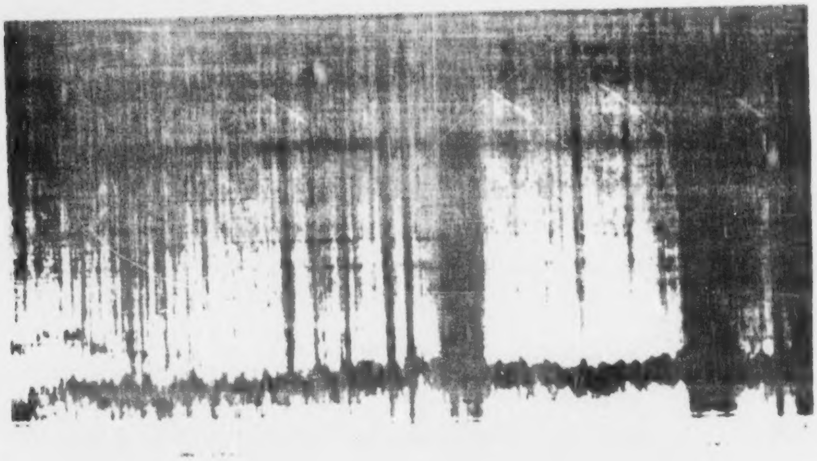


FIG. 2

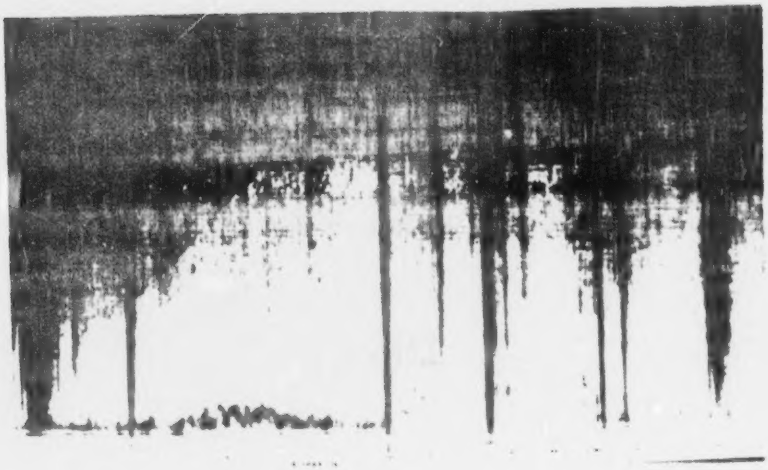


FIG. 3

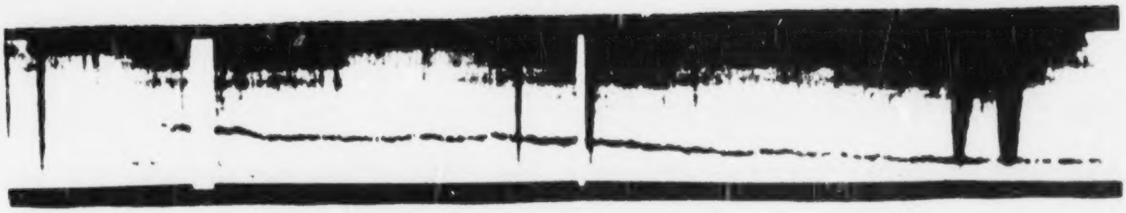


FIG. 4

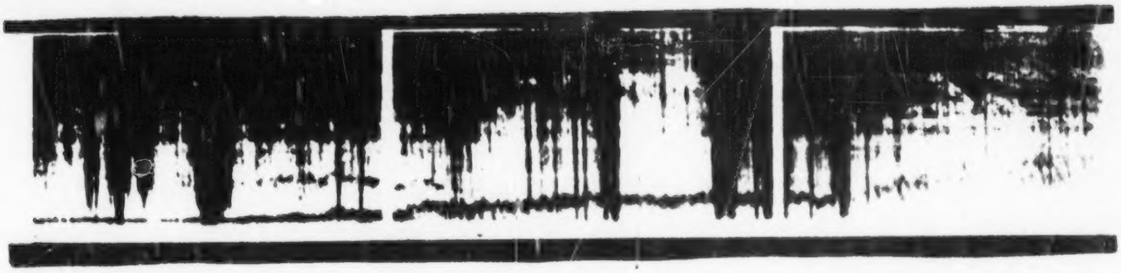


FIG. 5

FIG. 6

at the top is noise which has been amplified by the sounder electronics in an attempt to detect weaker signals at greater elevations. Vertical stripes are caused by noise from trains, cars, and motorcycles, and speckled regions arise from bird or insect noise.

Figure 1 shows a typical (at least for early spring) elevated inversion break-up in the early morning. At the left of the photo (6:30 AM) the inversion is well organized at about 250 m. As the morning progresses, undulations increase in amplitude until after 8:00 where the inversion is rapidly dissipating.

Figure 2 shows a fairly impervious layer at about 150 m that lifts slightly over the time period shown but remains intact through the morning hours, contrary to the more usual morning break-up. Figure 5 shows time periods on either side of those covered by Figure 2.

Figure 3 shows a ground-based inversion that experiences almost explosive break-up. The transition occurs over a one or two minute time period and appears to result in a near neutral or adiabatic state.

Figure 4 shows the most remarkable feature observed during the study period. A stable layer rapidly organizes into a very thin sheet at about 400 m around 9 PM. This layer is observed to slowly descend over a period of several hours and eventually reach ground (or near-ground) level.

This episode was accompanied by an intense ground-based fog which set in around 11 PM and persisted into the late morning hours creating enhanced CO and ozone levels in Des Moines on 19 March. Figure 6 shows the morning of the 19th from 8 AM to 1 PM CST. The persistence of this dispersion limiting feature is noteworthy and these observations concur with DEQ measurements of pollutant concentrations over this period.

Figure 6 is an expanded view of the details of the inversion break-up process.

The acoustic signatures reveal the atmospheric structure to be very complicated and subject to rapid change. We are gaining experience in interpreting sounder returns and full operation is currently continuing. It is our intent within the limits of manpower and resources available to continue to communicate real-time acoustic sounder observations to DEQ personnel for use in air quality management in Iowa.

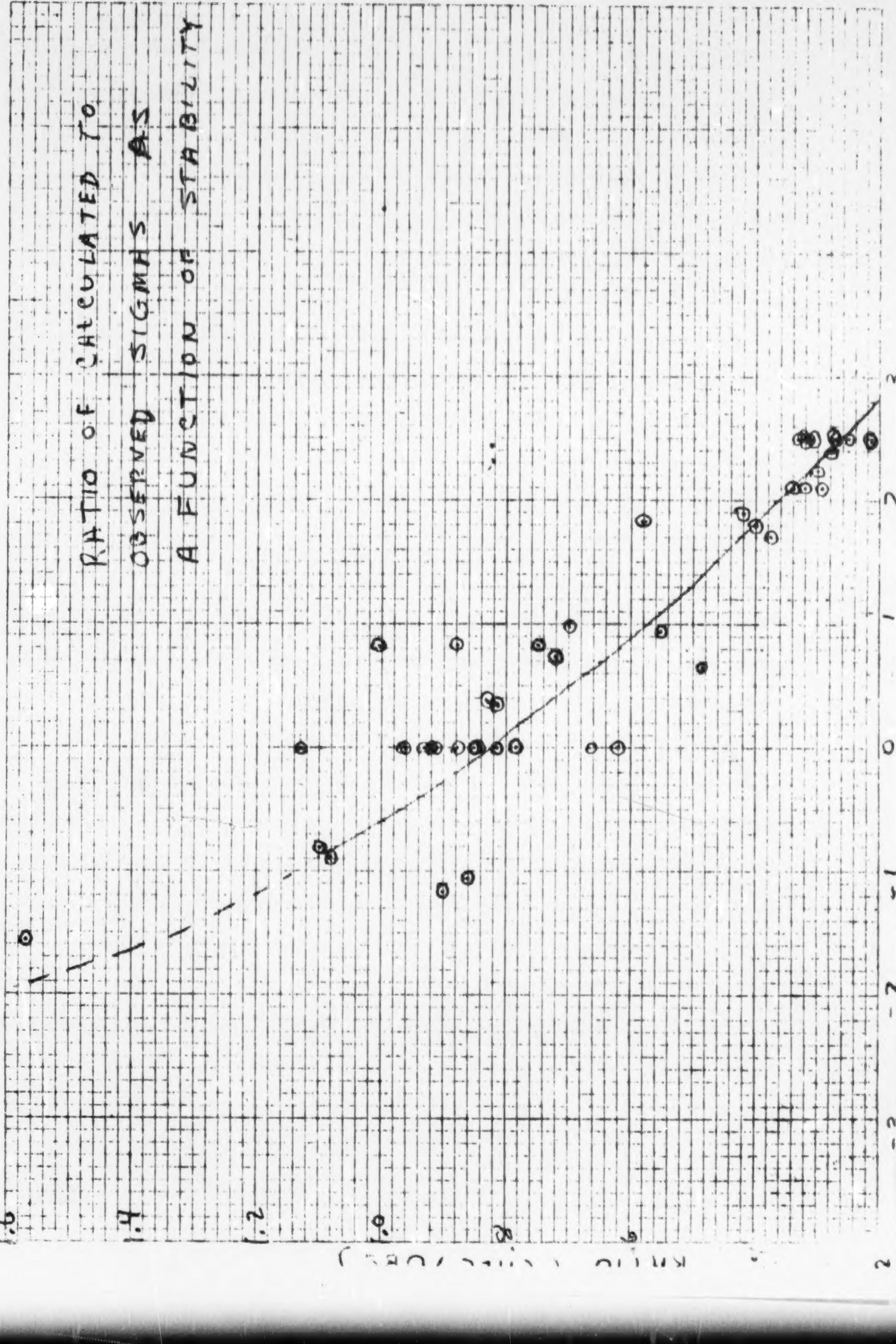
V. Photograph analysis

ISU personnel are assisting in the DEQ photograph analysis of plume pictures taken during the SO_2 study period. Measurements are made of the top and bottom of the plume at several downwind points or ten successive photos. These are then averaged to obtain the plume rise at each downwind point and the dispersion about the centerline. Sigma-z is then calculated from the relationship

$$\sigma_z(x) = W(x)/4.3$$

where W(x) is the width of the plume at downwind distance x. This is a direct consequence of the assumption that the visible edge of the plume has a pollutant concentration 10% of the centerline value.

Sigmas obtained in this manner are then compared with sigmas calculated using the methods of Turner. Preliminary results indicate Turner's method is best during neutral stability conditions but underestimates (overestimates) sigma-z during periods of stable (unstable) conditions. The ratio of calculated (by Turner's method) to observed varies from about .25 for extremely stable to about 1.5 for most unstable, with neutral stability giving a ratio of about 0.8. The accompanying graph shows a plot of the first 46 cases. The lack of data for unstable cases is expected because the SO_2 study period did not include the summer time situations.



RATIO OF CALCULATED TO OBSERVED SIGMAS AS A FUNCTION OF STABILITY

VI. Summary

The requested stability calculations have been carried out and supplied to DEQ. We have gone one step further and made calculations on climatological data for the central Iowa area to determine the pollutant dispersing capability of the atmosphere for seasons other than those covered by the SO_2 study.

The acoustic sounder has been constructed and successfully operated. Meteorological conditions contributing to air stagnation episodes have been vividly displayed.

This study has stimualted interest in continuing research on the dispersive characteristics of the atmosphere in Iowa. The Engineering Research Institute at ISU has earmarked $1800 for continued support of the acoustic sounder program. The Agriculture Experiment Station has committed $2000 to continuing support of this research. A $239,000 proposal to significantly expand these studies is under consideration by the U.S. Energy Research and Development Administration.

It is our hope that the results of research presented here and from future studies we are contemplating will contribute to the maintenance of a clean atmospheric environment in the state of Iowa and hence to the good health and well-being of its citizenry.

VII. Bibliography

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